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(12) **United States Patent**  
**Owen et al.**

(10) **Patent No.:** **US 10,702,694 B2**  
(45) **Date of Patent:** **Jul. 7, 2020**

(54) **SYSTEMS, DEVICES, AND METHODS FOR TREATING VESTIBULAR CONDITIONS**

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**Related U.S. Application Data**  
(60) Division of application No. 15/982,867, filed on May 17, 2018, now Pat. No. 10,398,897, which is a (Continued)

(51) **Int. Cl.**  
**A61H 23/02** (2006.01)  
**A61N 1/36** (2006.01)  
(Continued)

(52) **U.S. Cl.**  
CPC ..... **A61N 1/36036** (2017.08); **A61B 5/4023** (2013.01); **A61B 5/6814** (2013.01);  
(Continued)

(58) **Field of Classification Search**  
CPC .... A61H 23/00; A61H 23/02; A61H 23/0218; A61H 23/0236; A61H 2201/5005;  
(Continued)

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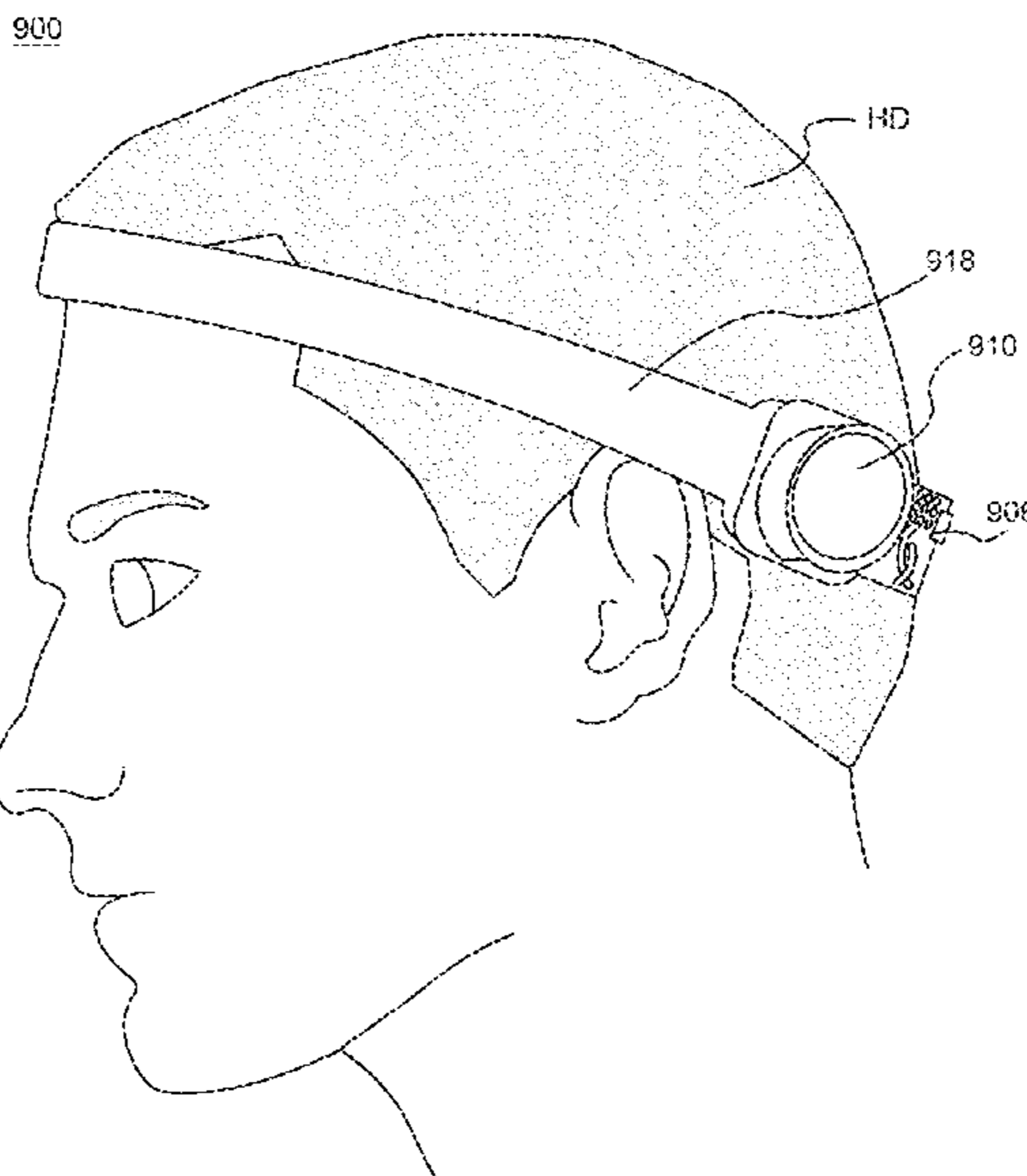
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(74) *Attorney, Agent, or Firm* — Cooley LLP

(57) **ABSTRACT**

Apparatus and methods are described herein that provide a vibratory device that can apply a vibratory signal to a portion of a head of a user such that the vibratory signal can be conducted via bone to a vestibular system of the user and cause a portion of the vestibular system to move in a manner equivalent to that of a therapeutically effective vibratory signal applied to an area overlaying a mastoid bone of the user. The vibratory device can be associated with frequencies less than 200 Hz. The vibratory device can be effective at treating a physiological condition associated with the vestibular system.

**25 Claims, 28 Drawing Sheets**



**Related U.S. Application Data**

continuation-in-part of application No. 15/481,457, filed on Apr. 7, 2017.

(60) Provisional application No. 62/421,708, filed on Nov. 14, 2016, provisional application No. 62/629,197, filed on Feb. 12, 2018, provisional application No. 62/629,213, filed on Feb. 12, 2018.

(51) **Int. Cl.**

*A61B 5/00* (2006.01)  
*A61F 11/04* (2006.01)  
*A61F 11/00* (2006.01)  
*A61M 21/00* (2006.01)  
*A61N 7/00* (2006.01)  
*H04R 5/033* (2006.01)  
*H04R 5/02* (2006.01)

(52) **U.S. Cl.**

CPC ..... *A61F 11/00* (2013.01); *A61F 11/04* (2013.01); *A61M 21/00* (2013.01); *A61N 7/00* (2013.01); *A61B 5/4836* (2013.01); *A61B 5/6803* (2013.01); *A61B 5/6893* (2013.01); *A61M 2021/005* (2013.01); *A61M 2021/0022* (2013.01); *A61M 2021/0027* (2013.01); *A61M 2021/0044* (2013.01); *A61M 2205/332* (2013.01); *A61M 2205/507* (2013.01); *A61M 2230/06* (2013.01); *A61M 2230/205* (2013.01); *A61M 2230/50* (2013.01); *A61M 2230/63* (2013.01); *A61M 2230/65* (2013.01); *A61N 2007/0026* (2013.01); *A61N 2007/0043* (2013.01); *H04R 5/023* (2013.01); *H04R 5/033* (2013.01); *H04R 2460/13* (2013.01)

(58) **Field of Classification Search**

CPC ..... A61H 2201/5048; H04R 2400/03; H04R 2400/07; H04R 2460/13; H04R 25/606; H04R 25/75

USPC ..... 381/326, 380, 151

See application file for complete search history.

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Waveform generated by Medium Surface Transducer with Wires—4 Ohm 3 Watt, generated on Apr. 11, 2018, 1 page.

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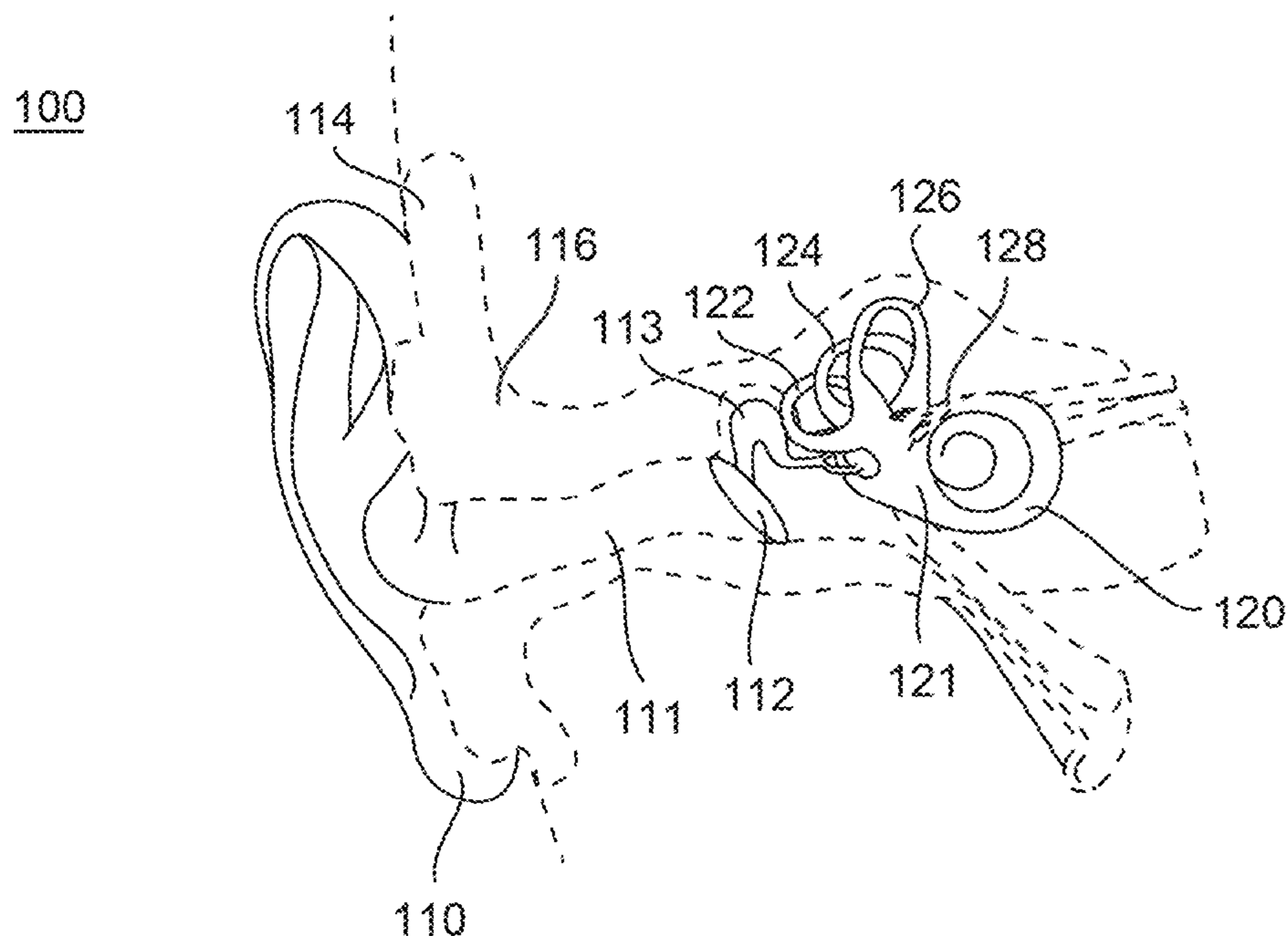


FIG. 1A

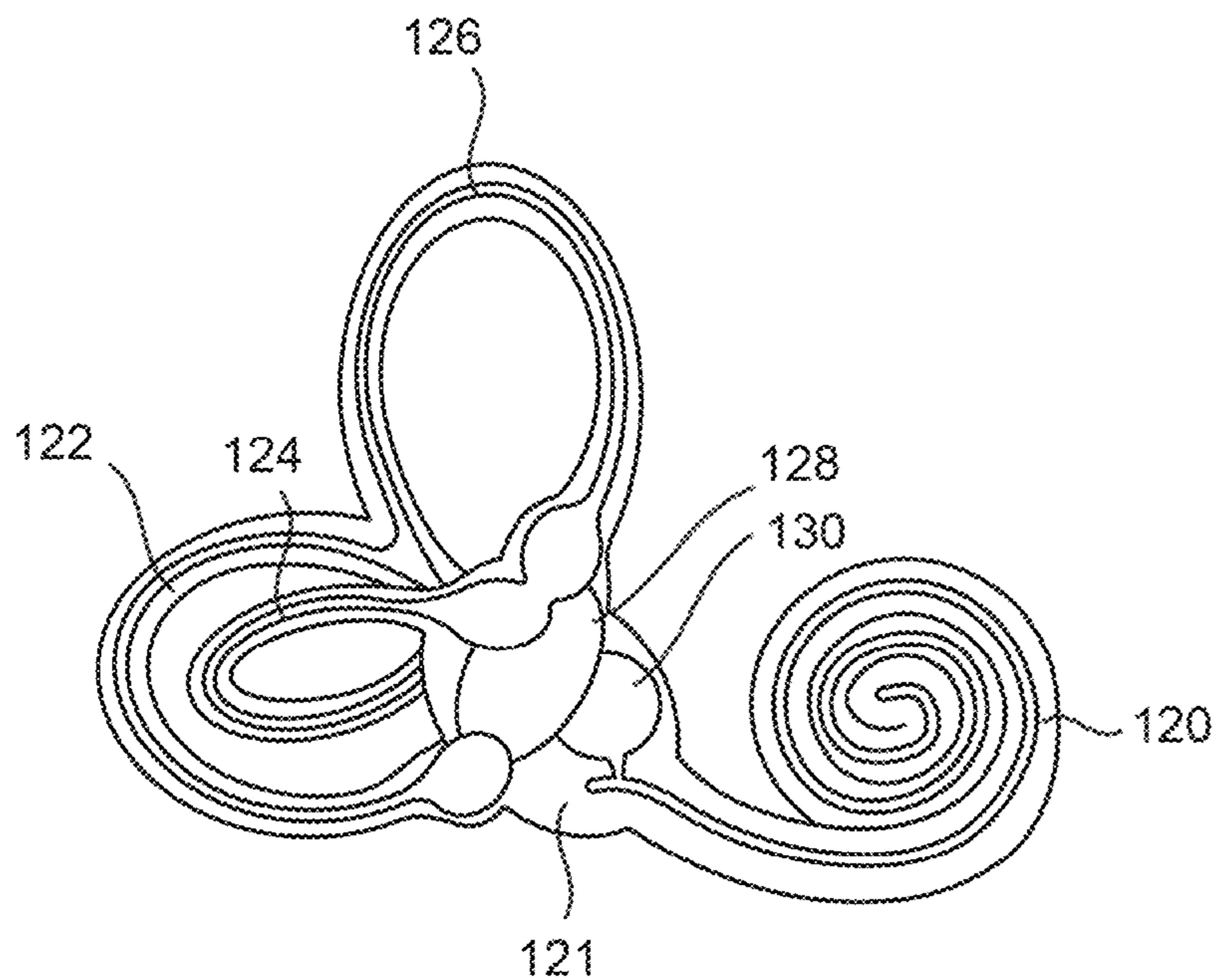


FIG. 1B

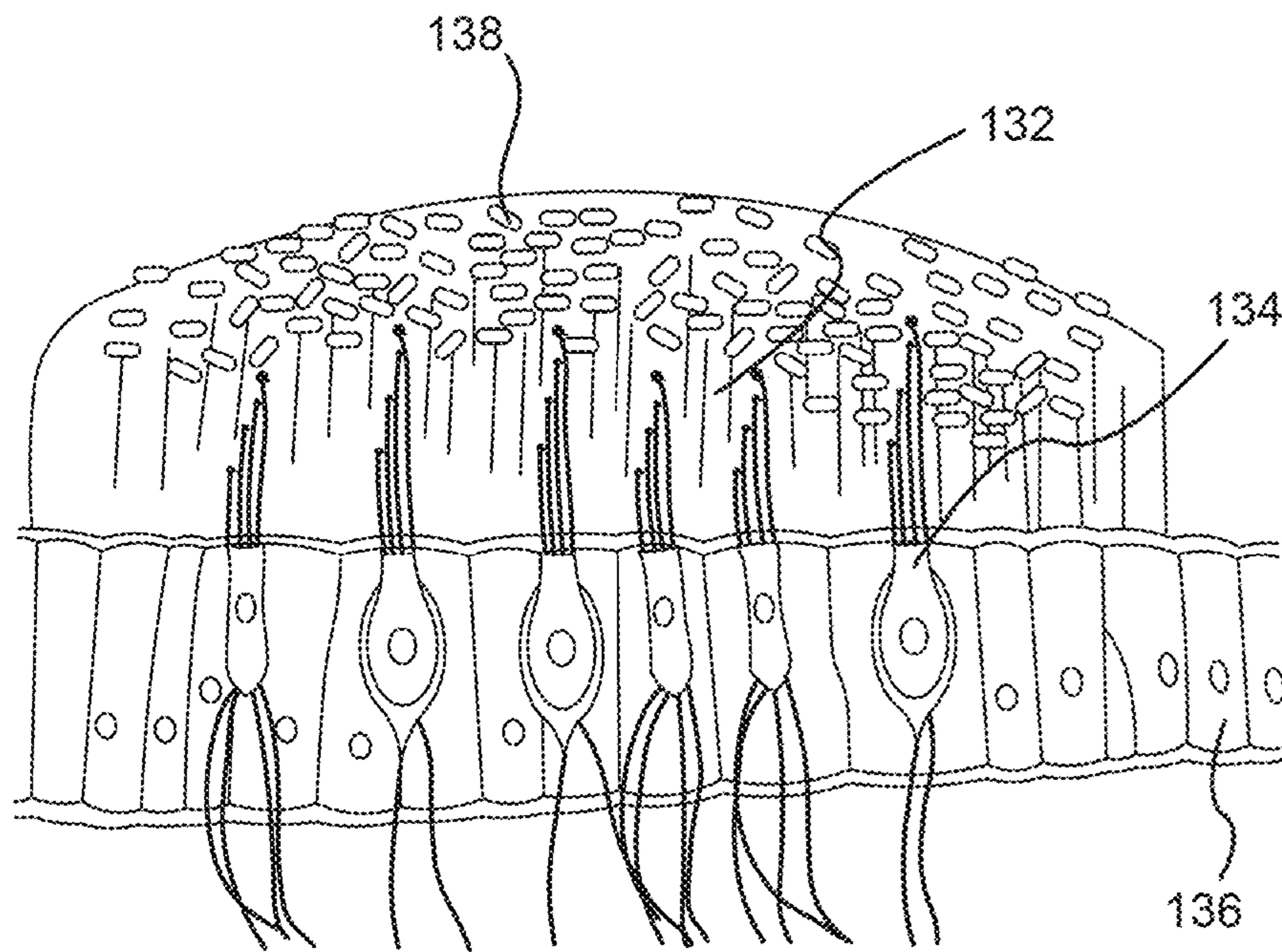


FIG. 2A

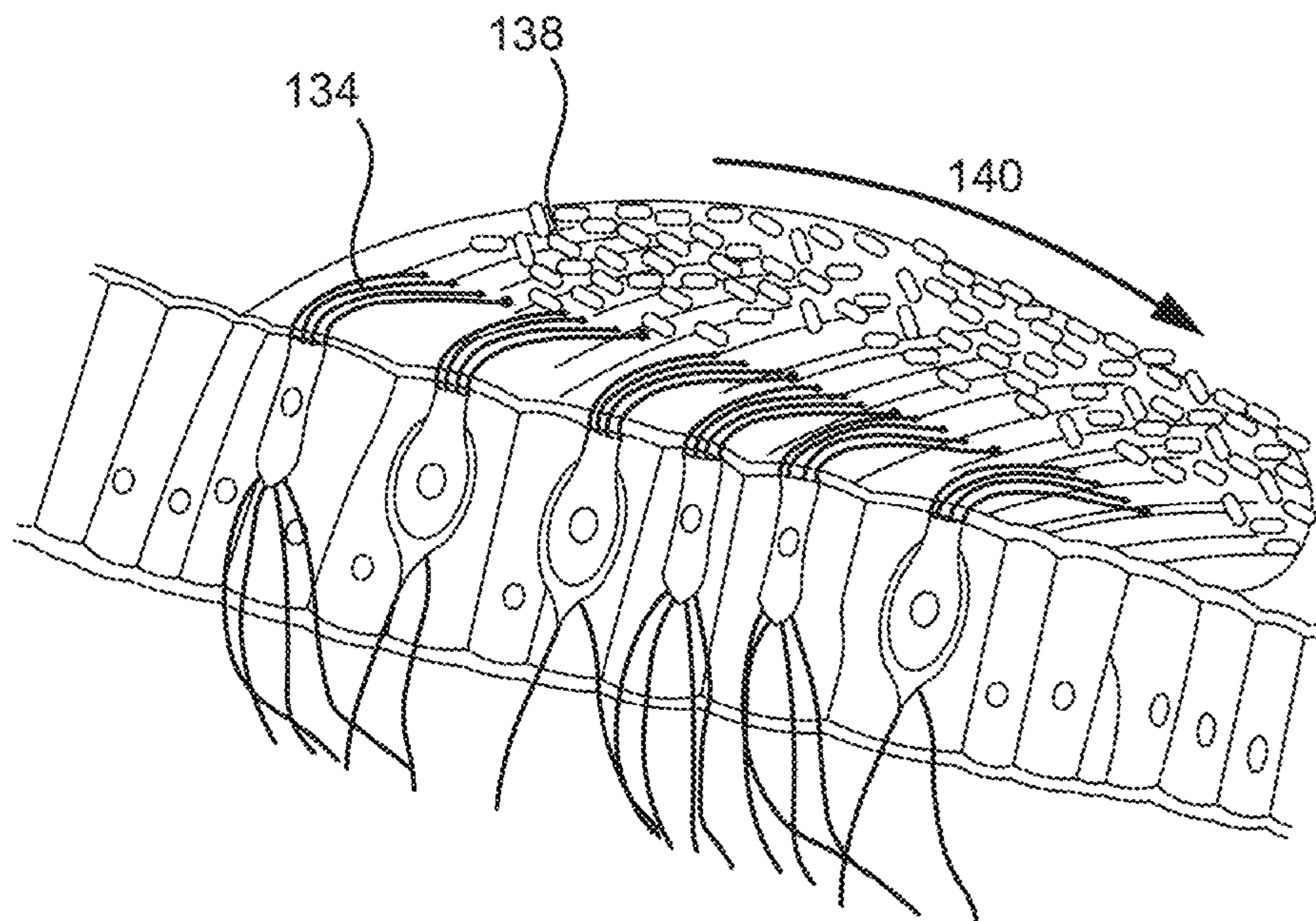


FIG. 2B

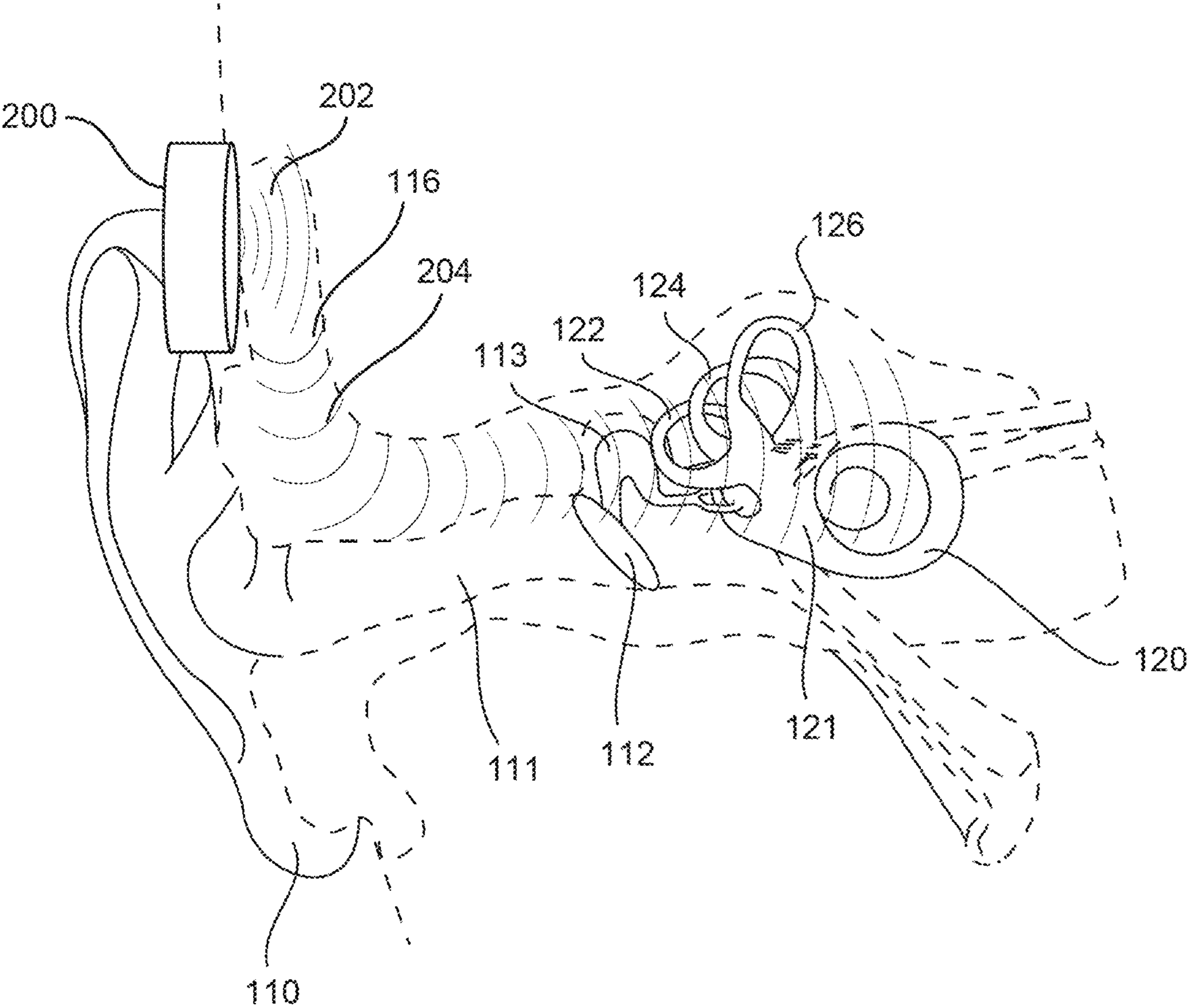


FIG. 3

350

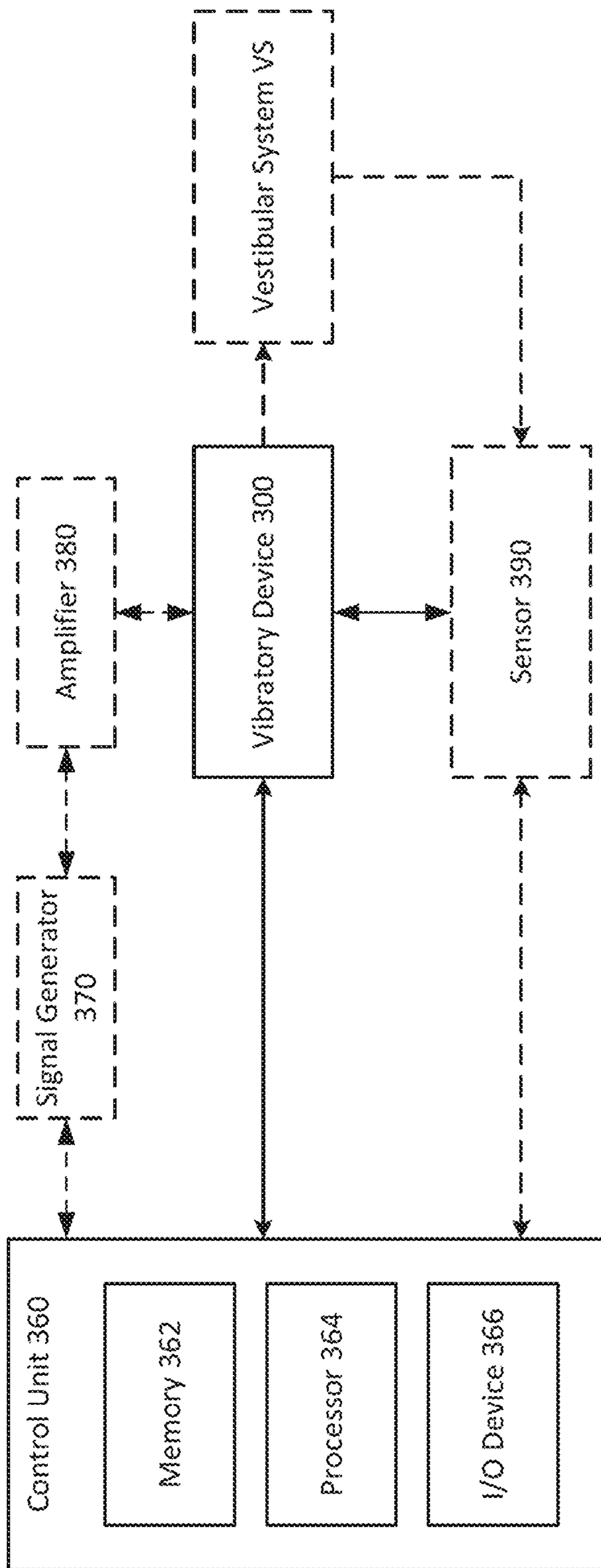


FIG. 4A

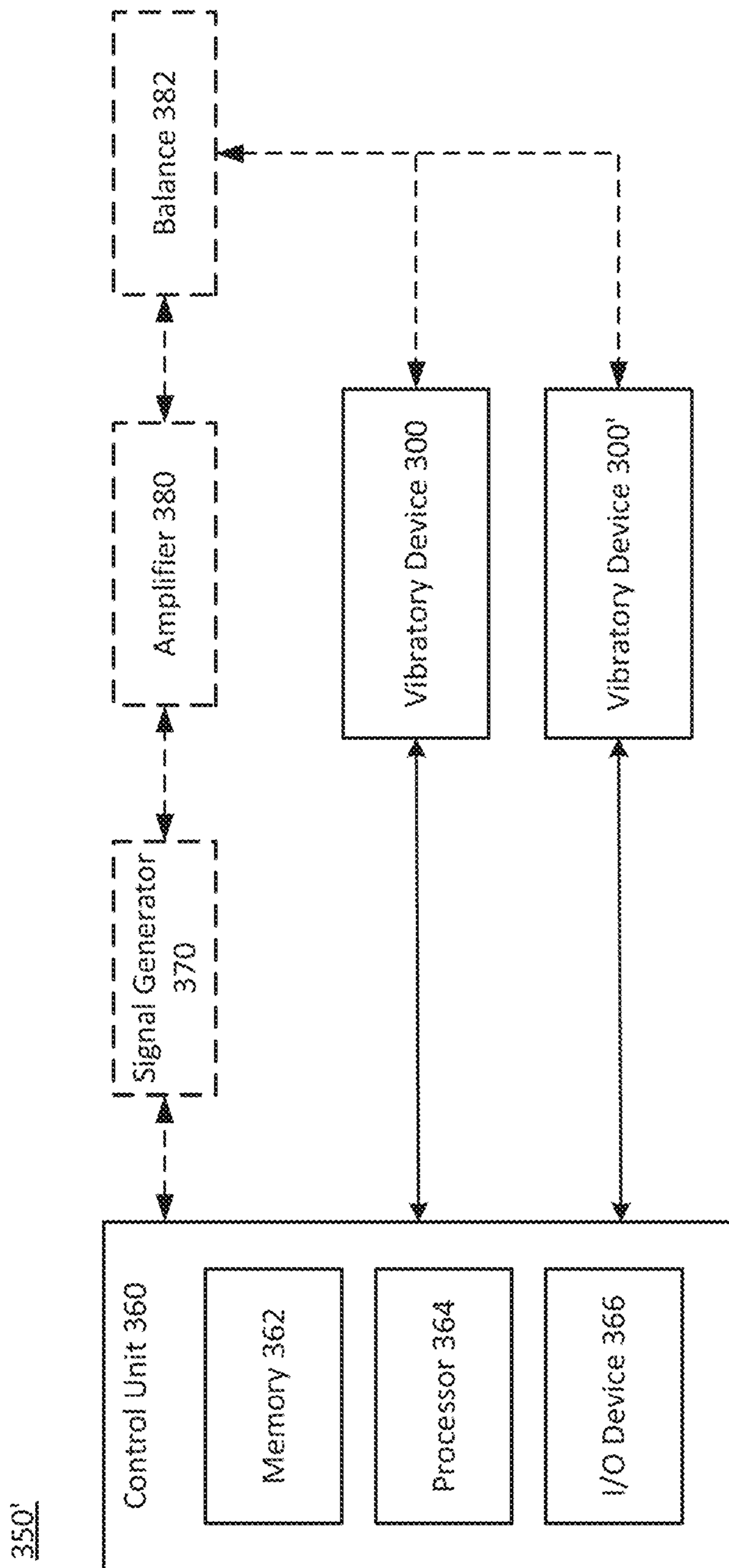


FIG. 4B



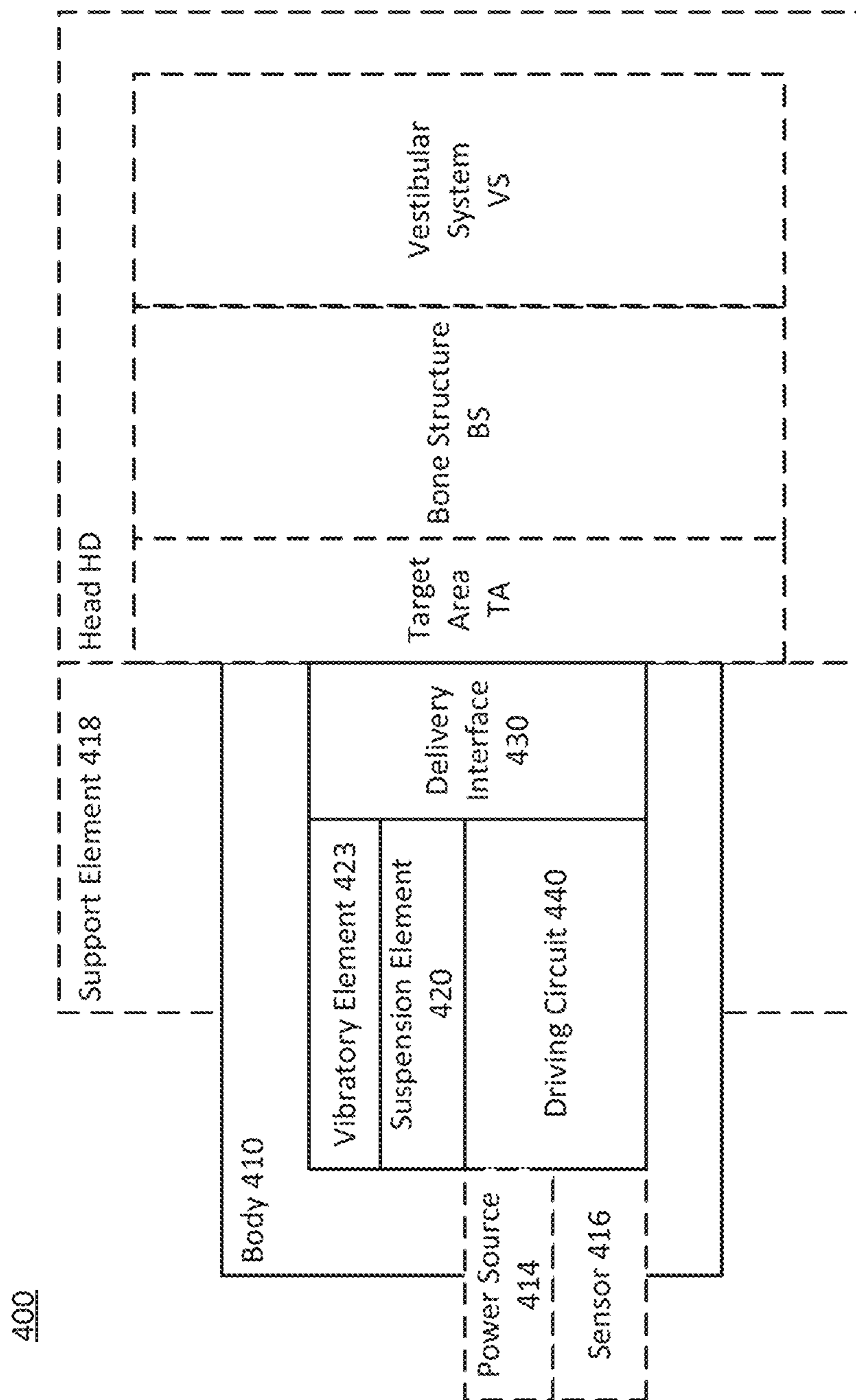


FIG. 5

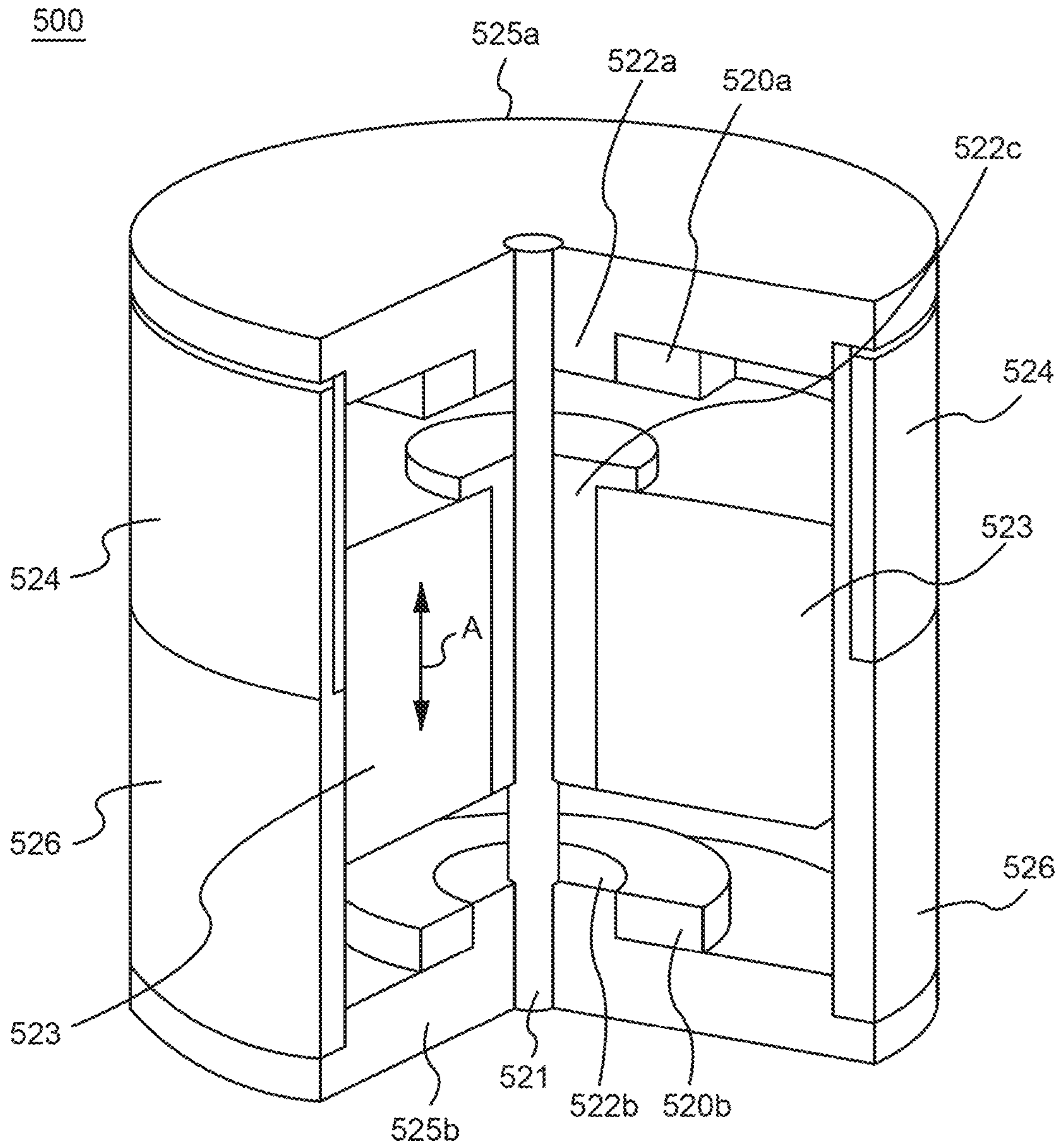


FIG. 6

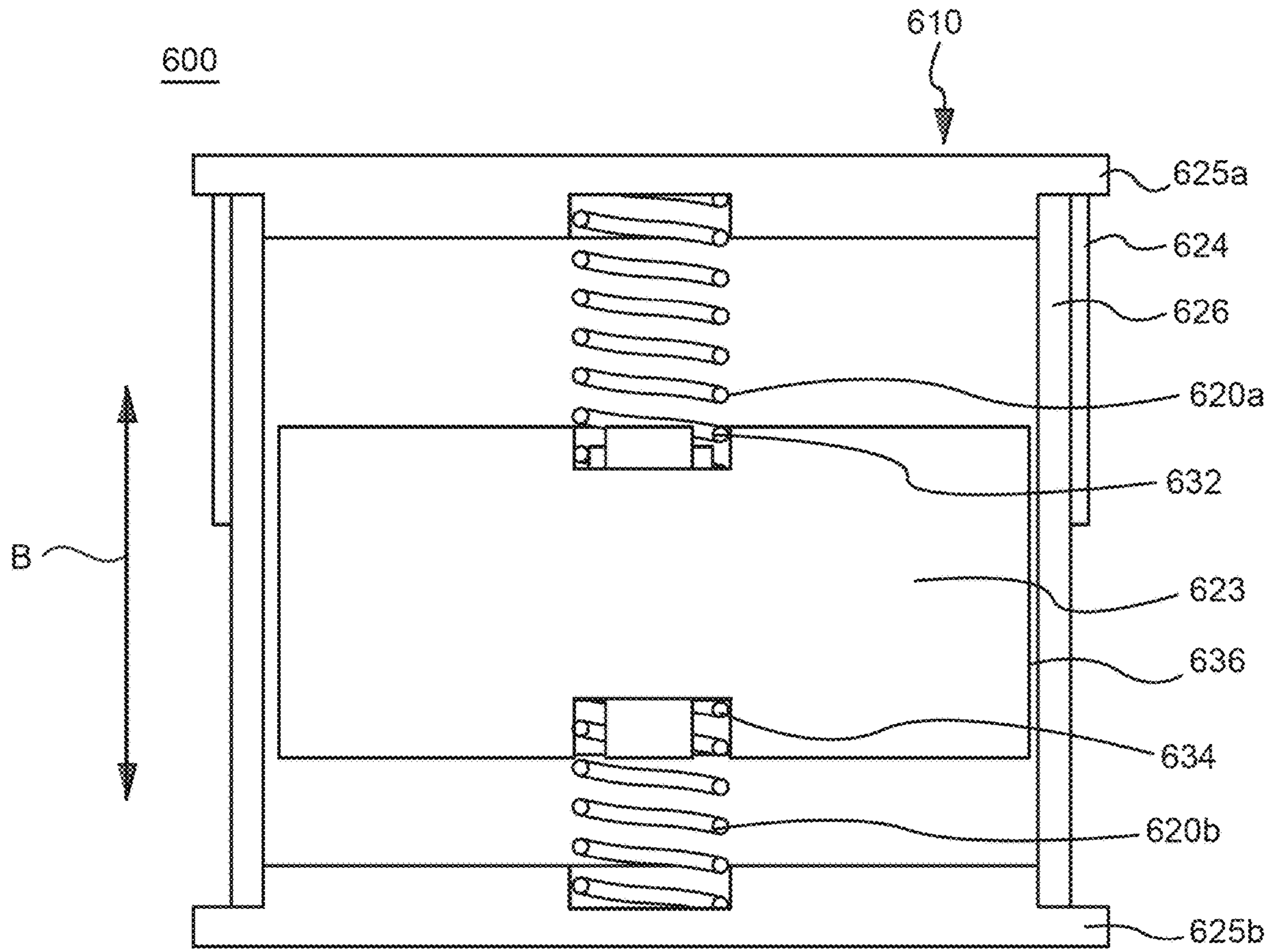


FIG. 7A

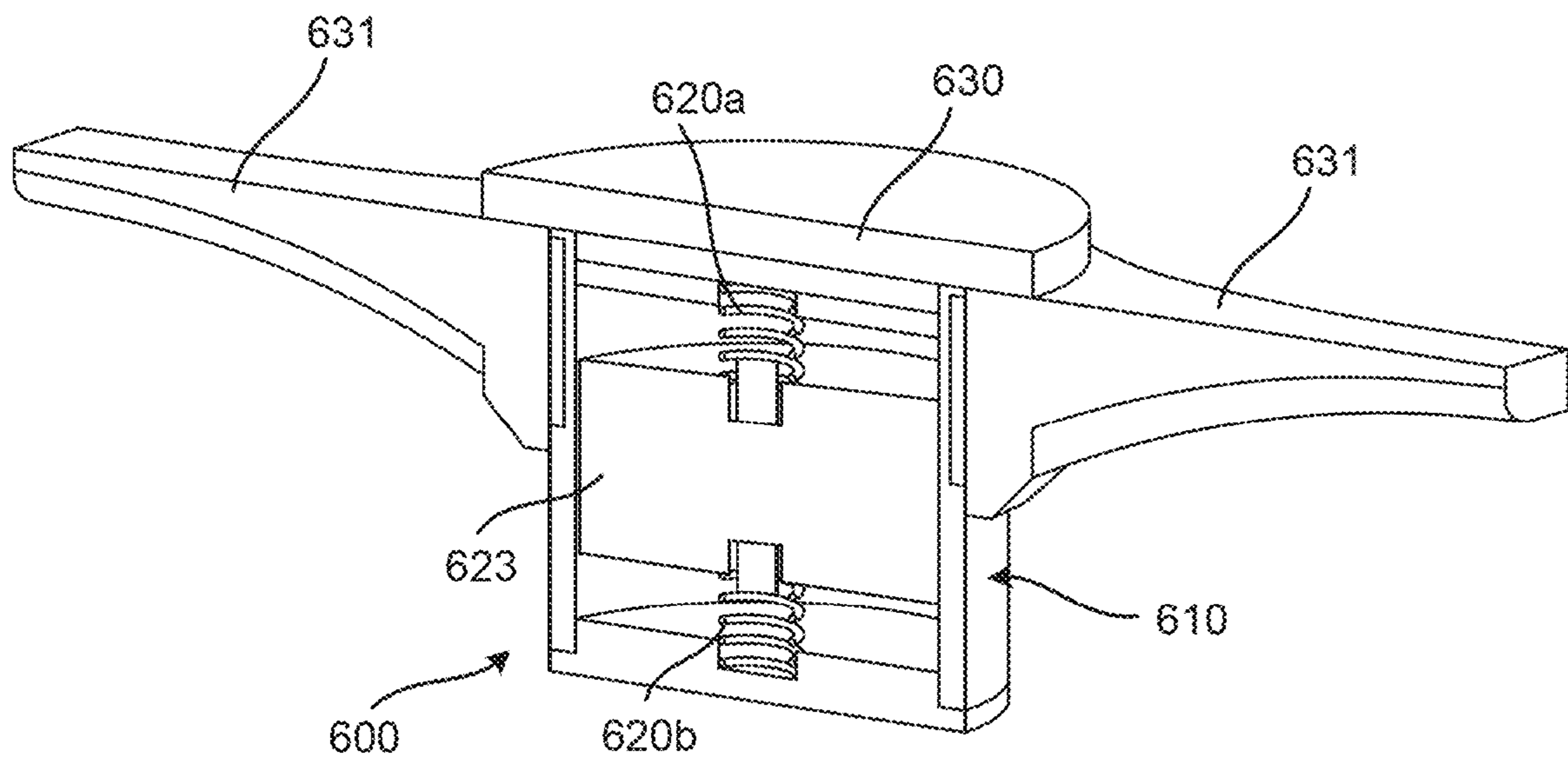


FIG. 7B

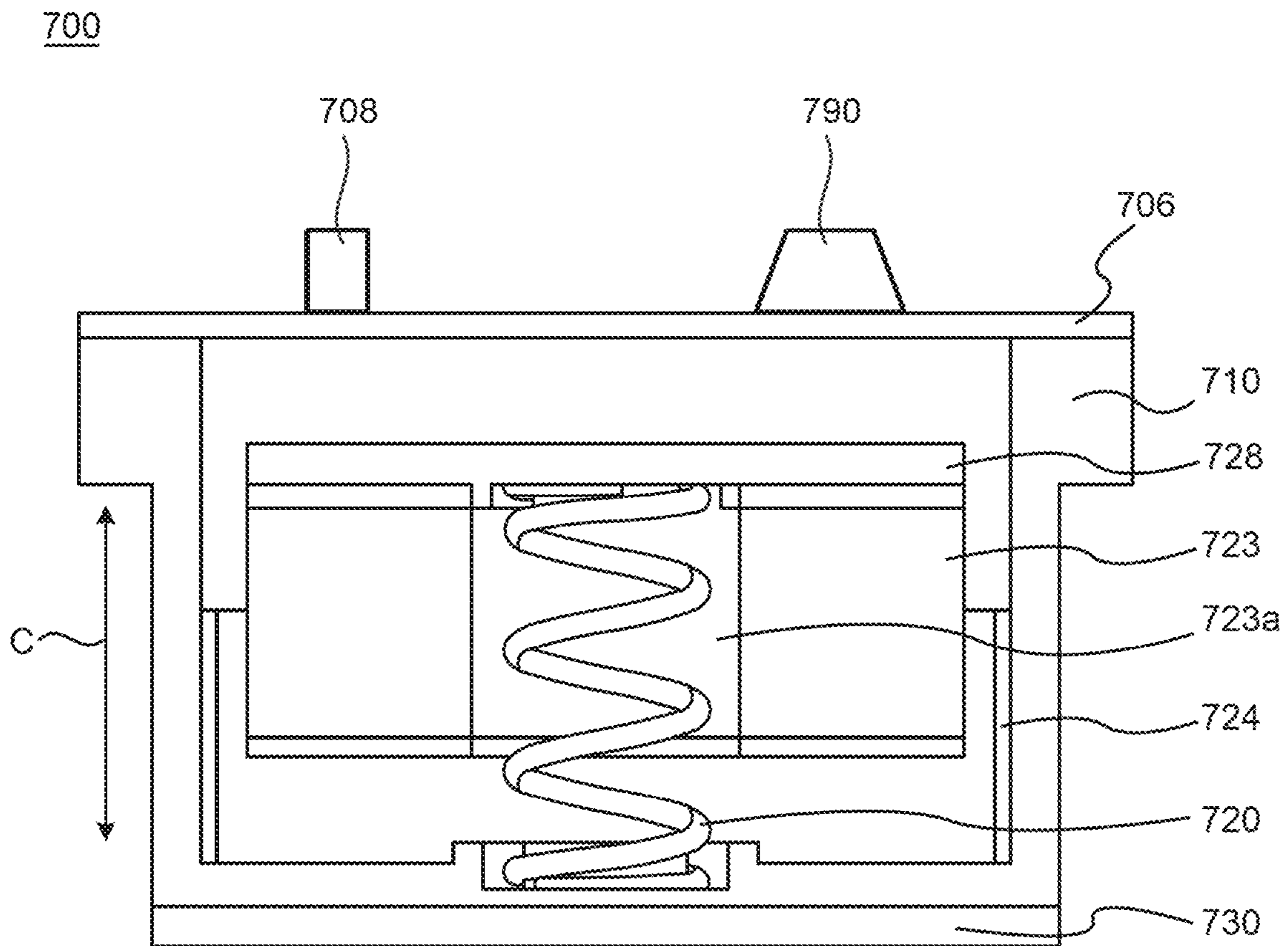


FIG. 8

820

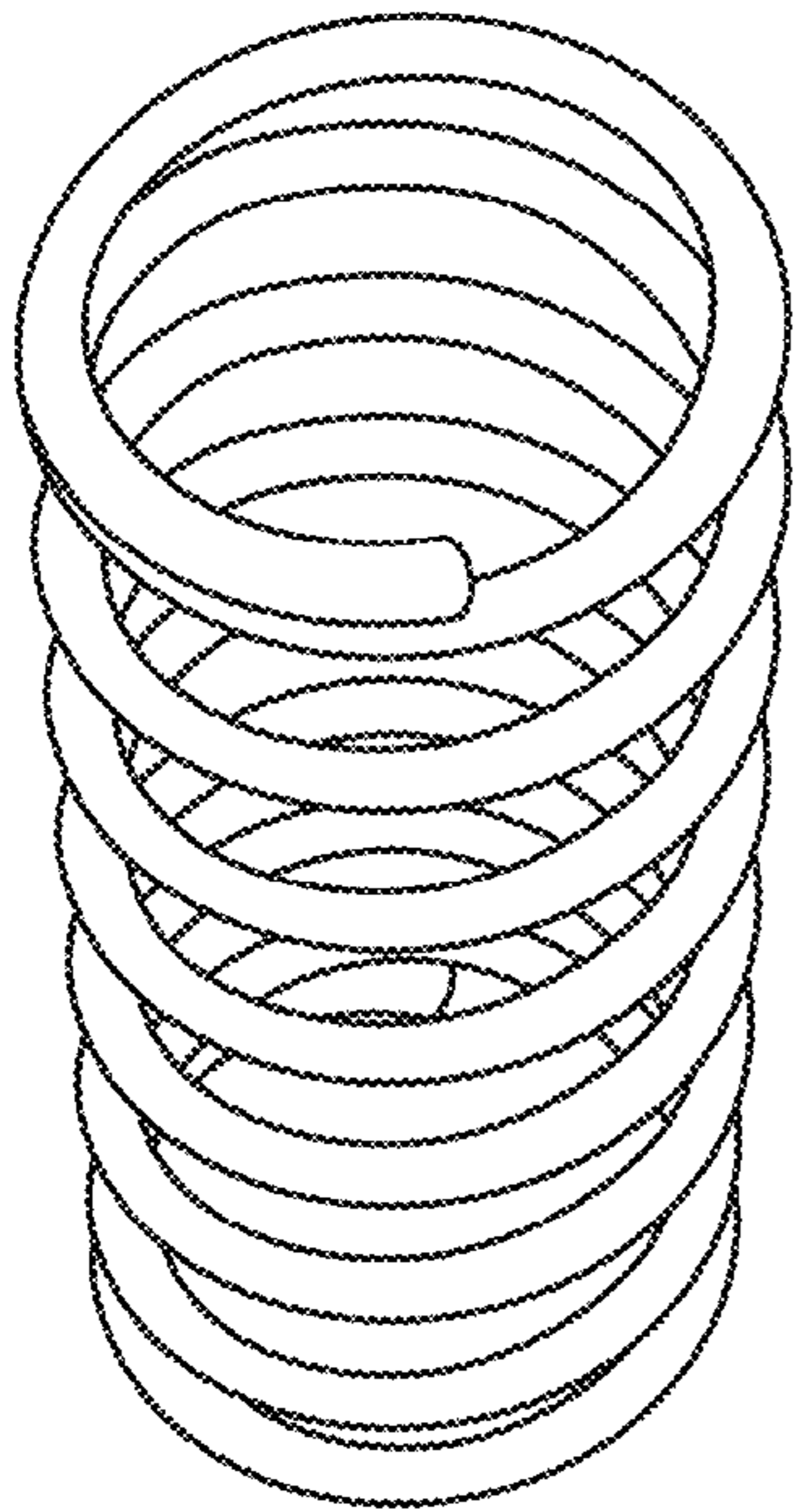


FIG. 9A

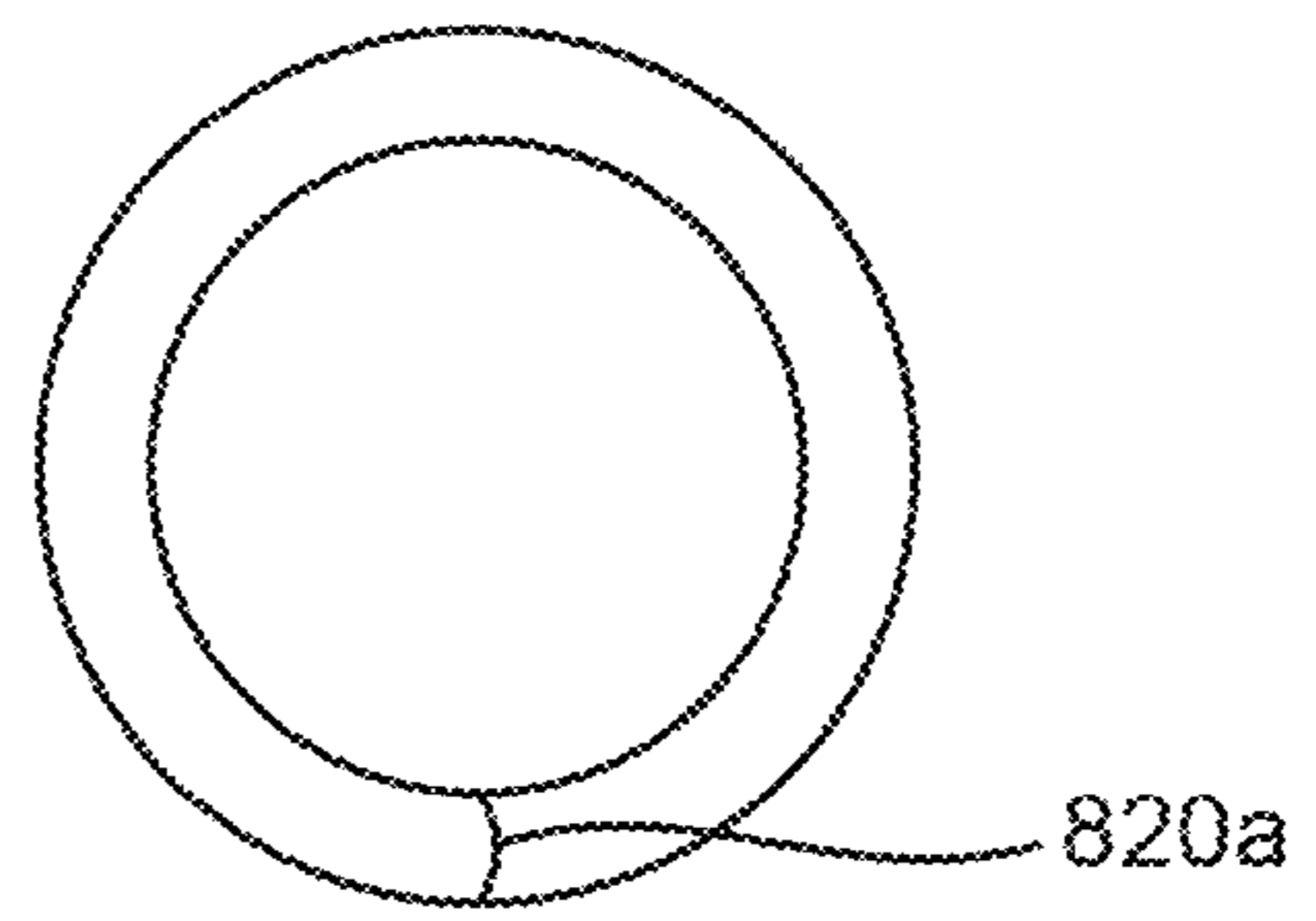


FIG. 9B

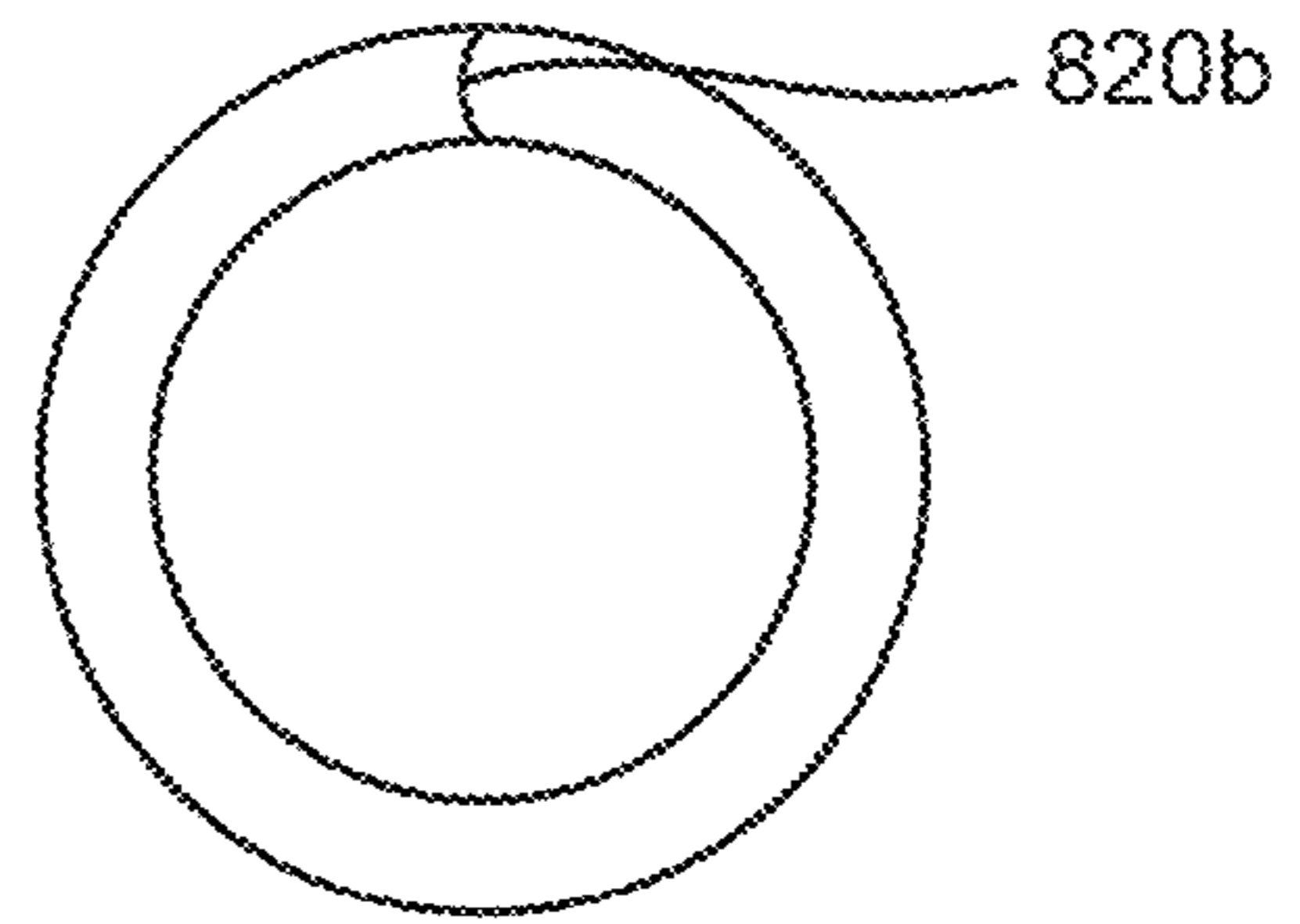


FIG. 9C

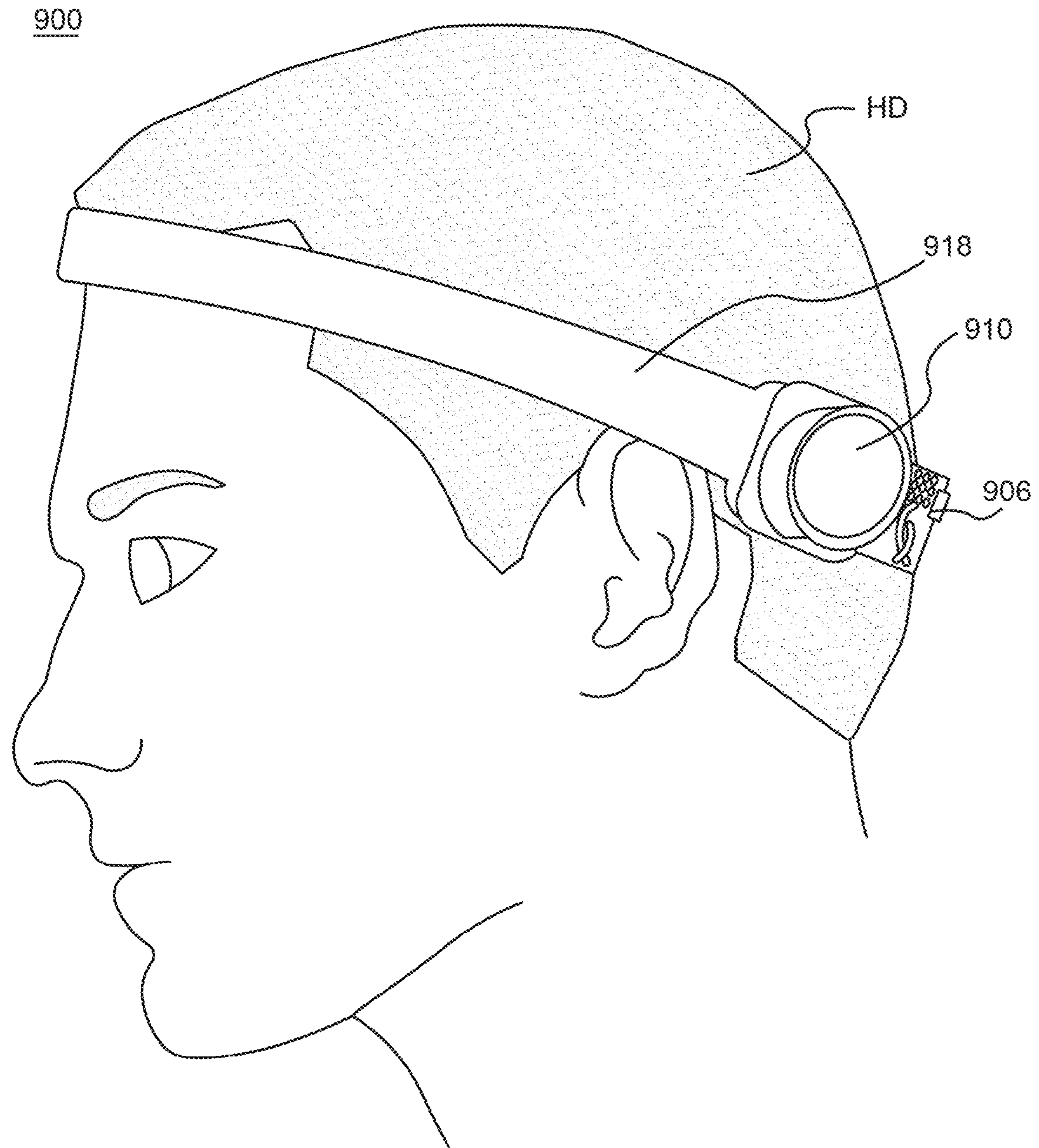


FIG. 10

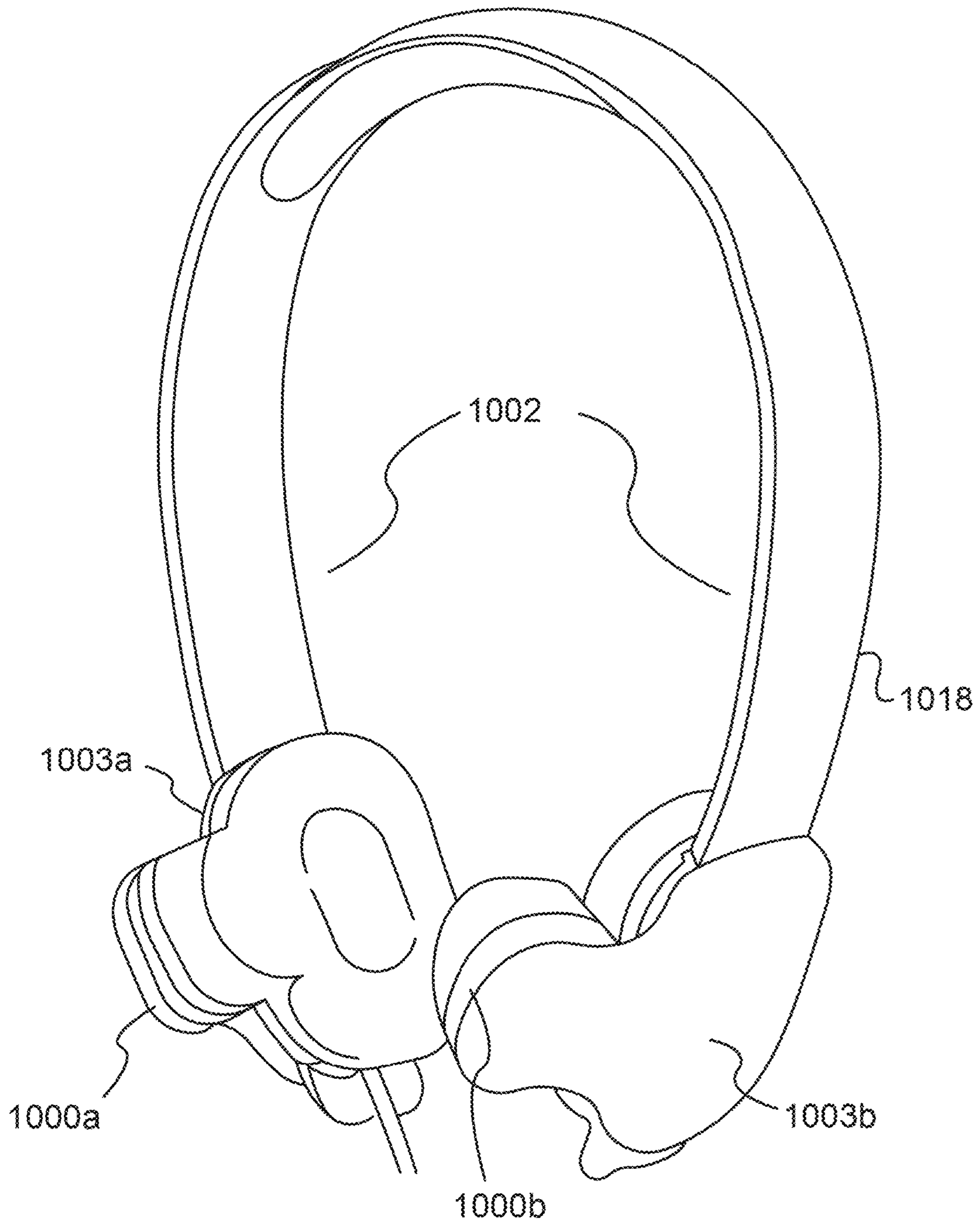


FIG. 11



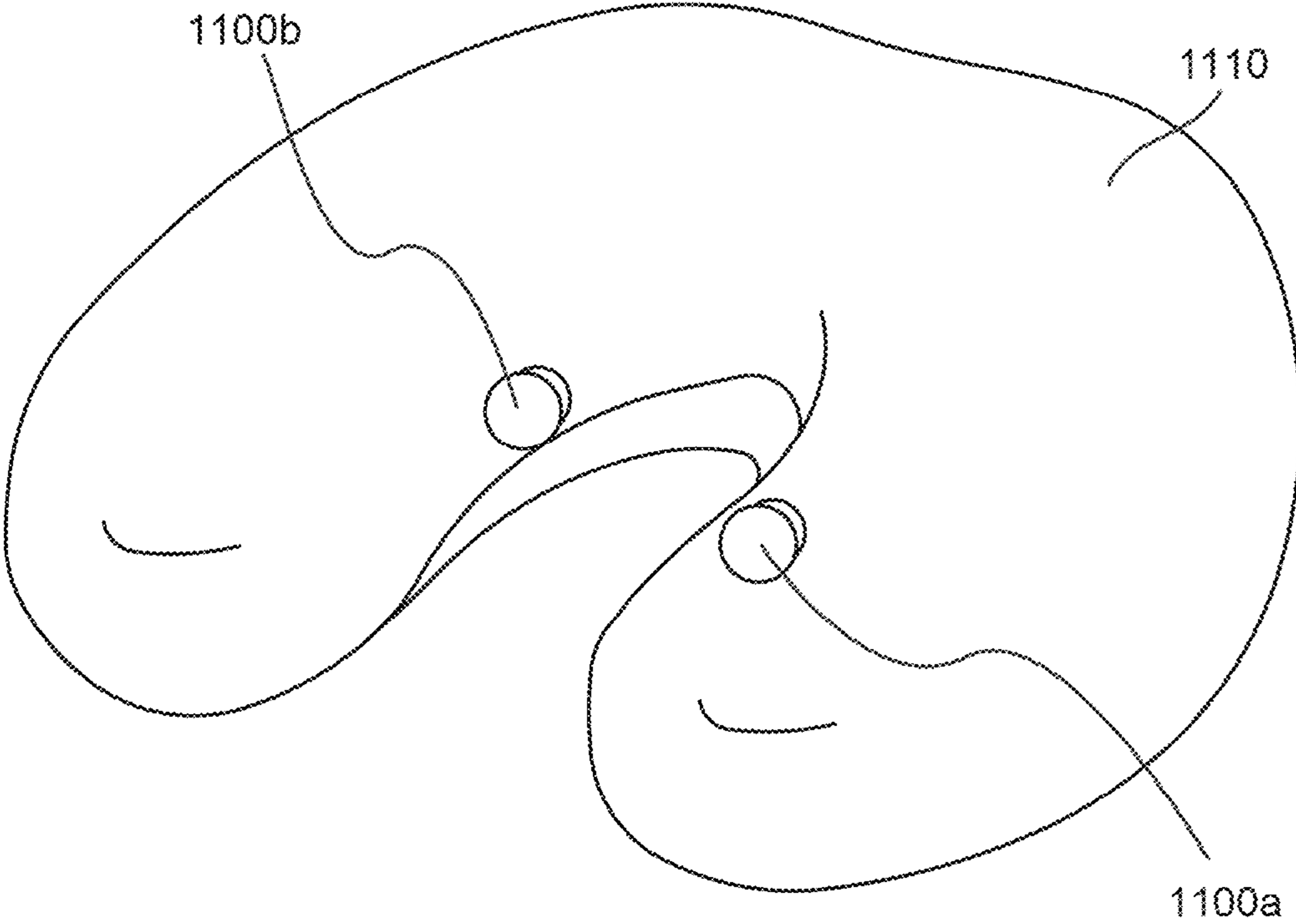


FIG. 12

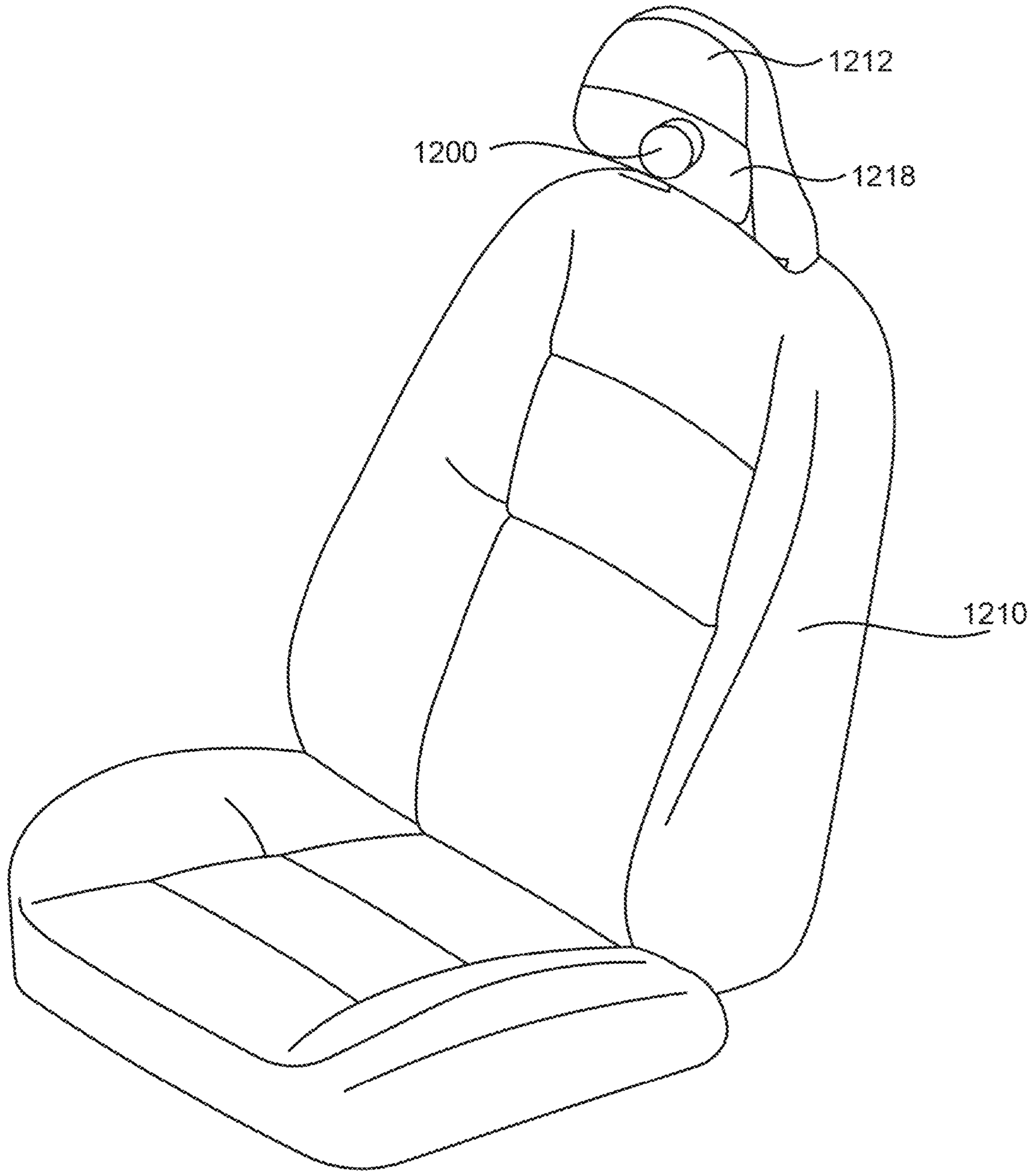


FIG. 13

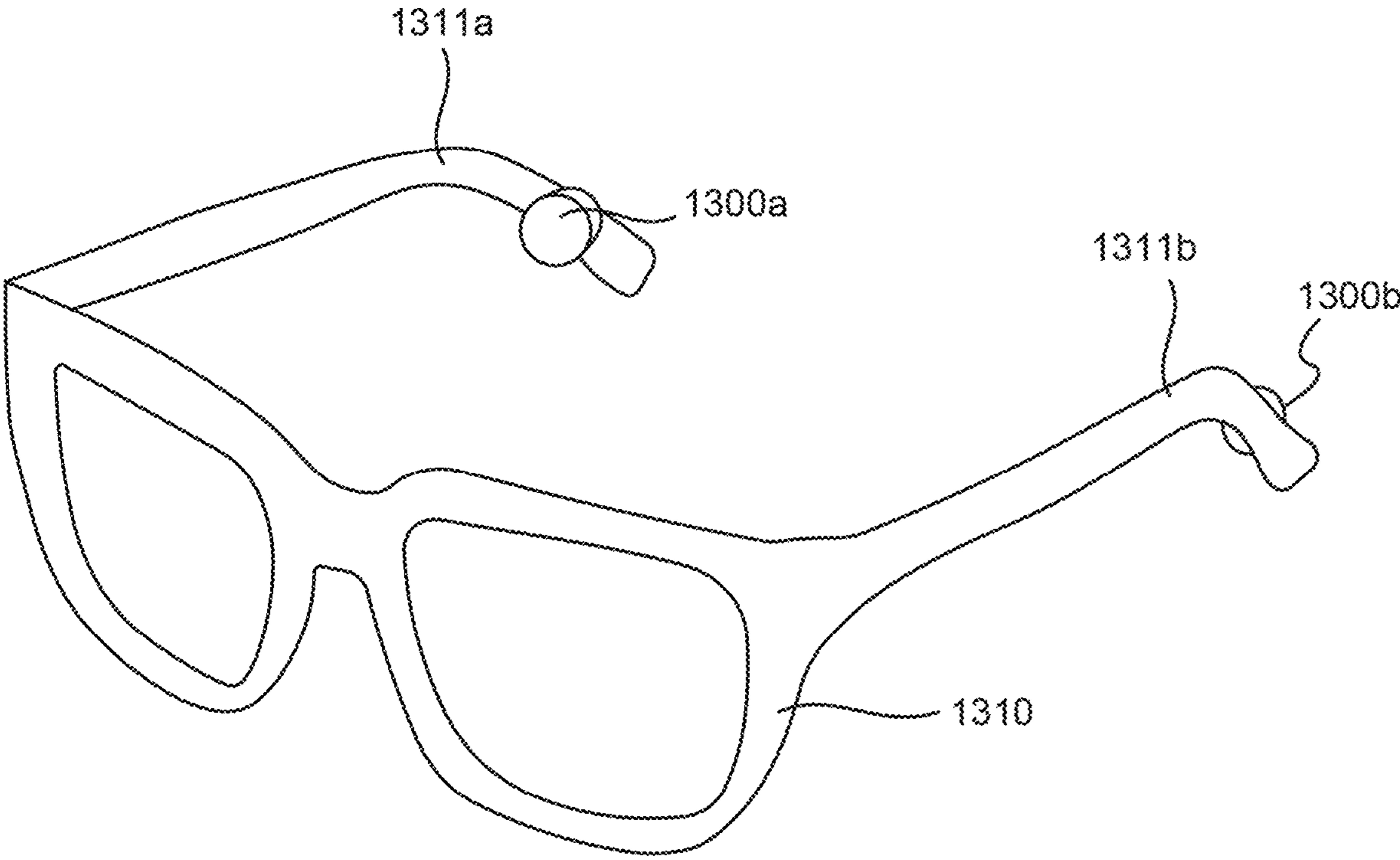


FIG. 14

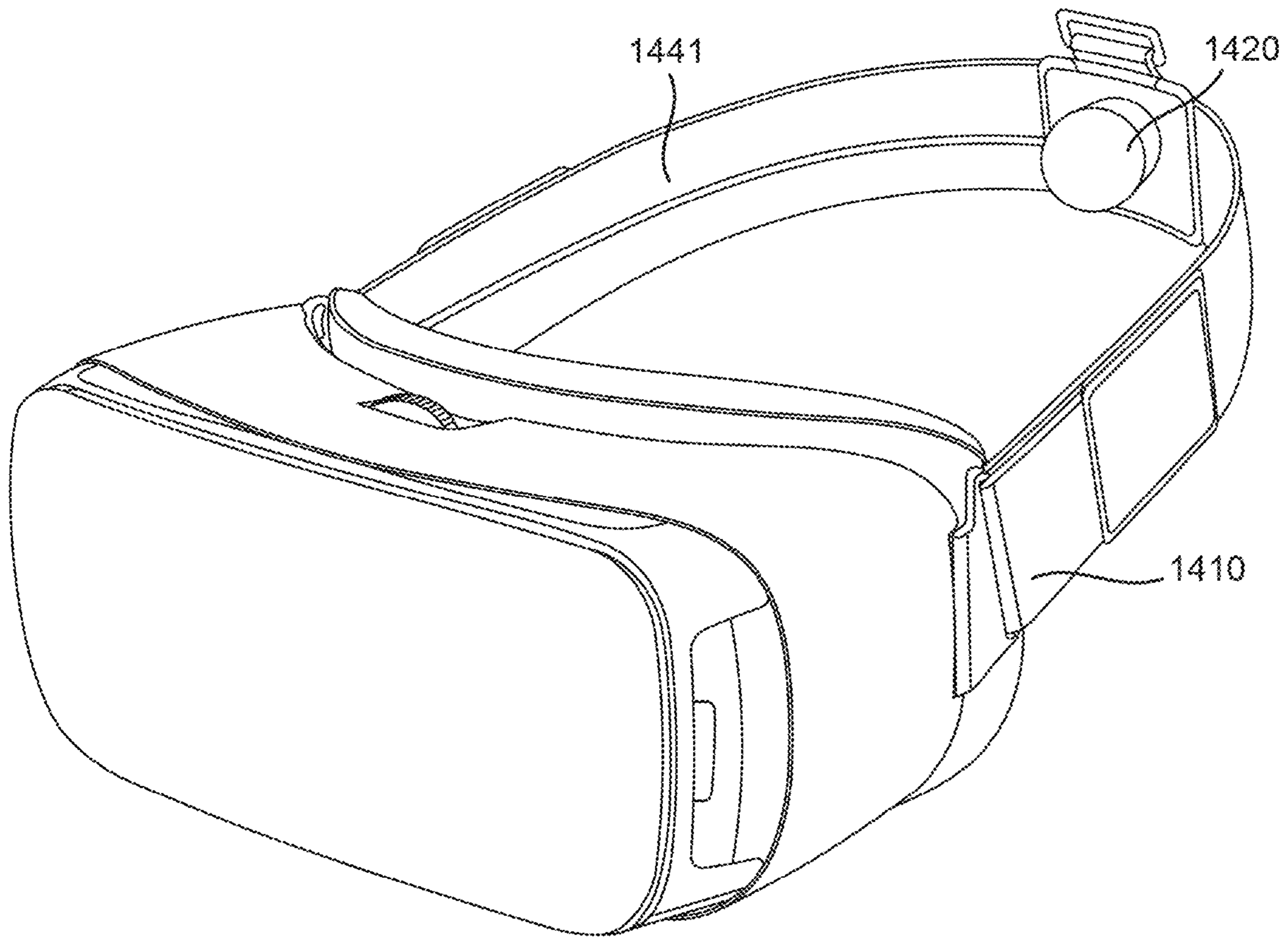


FIG. 15

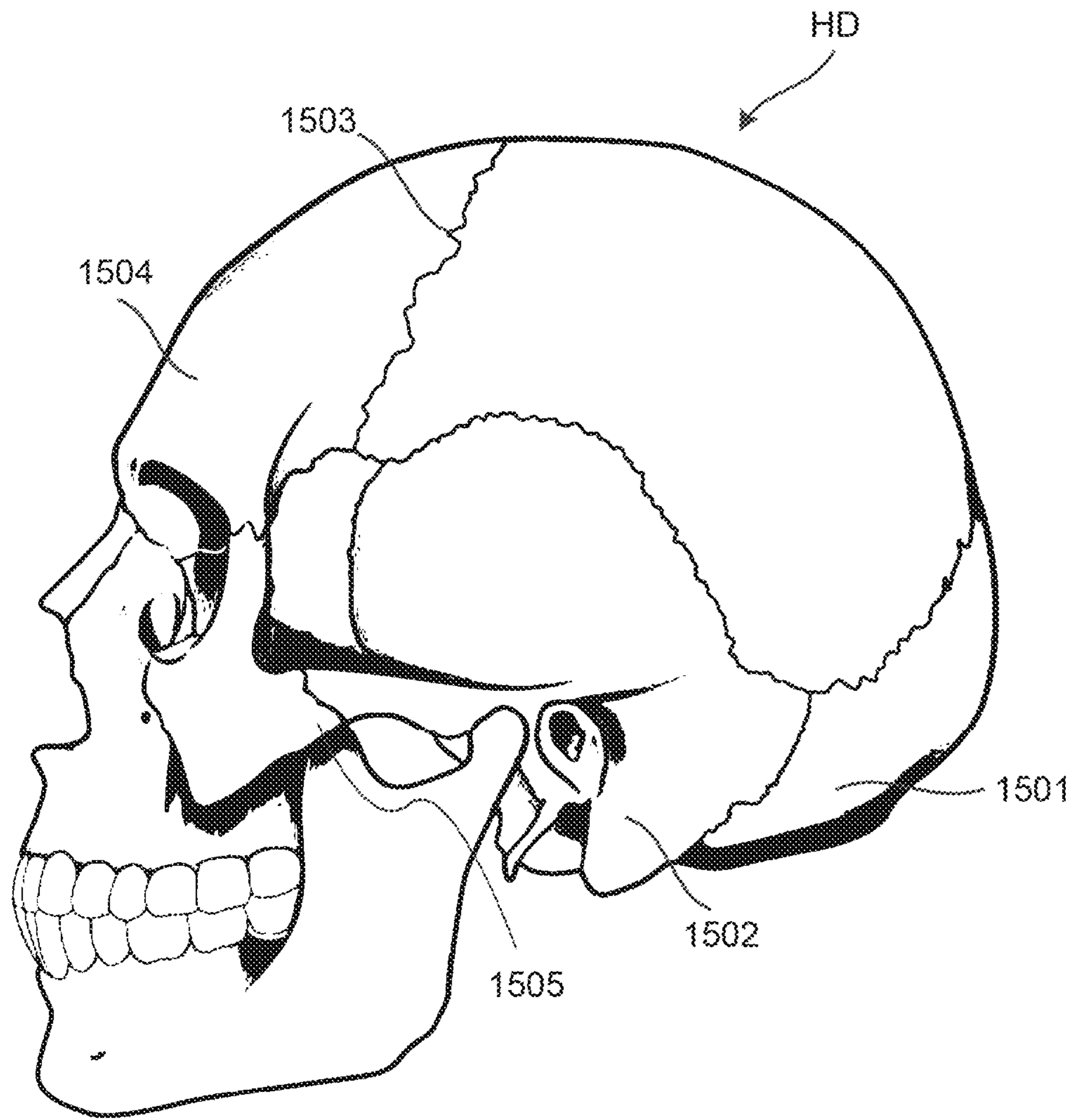


FIG. 16

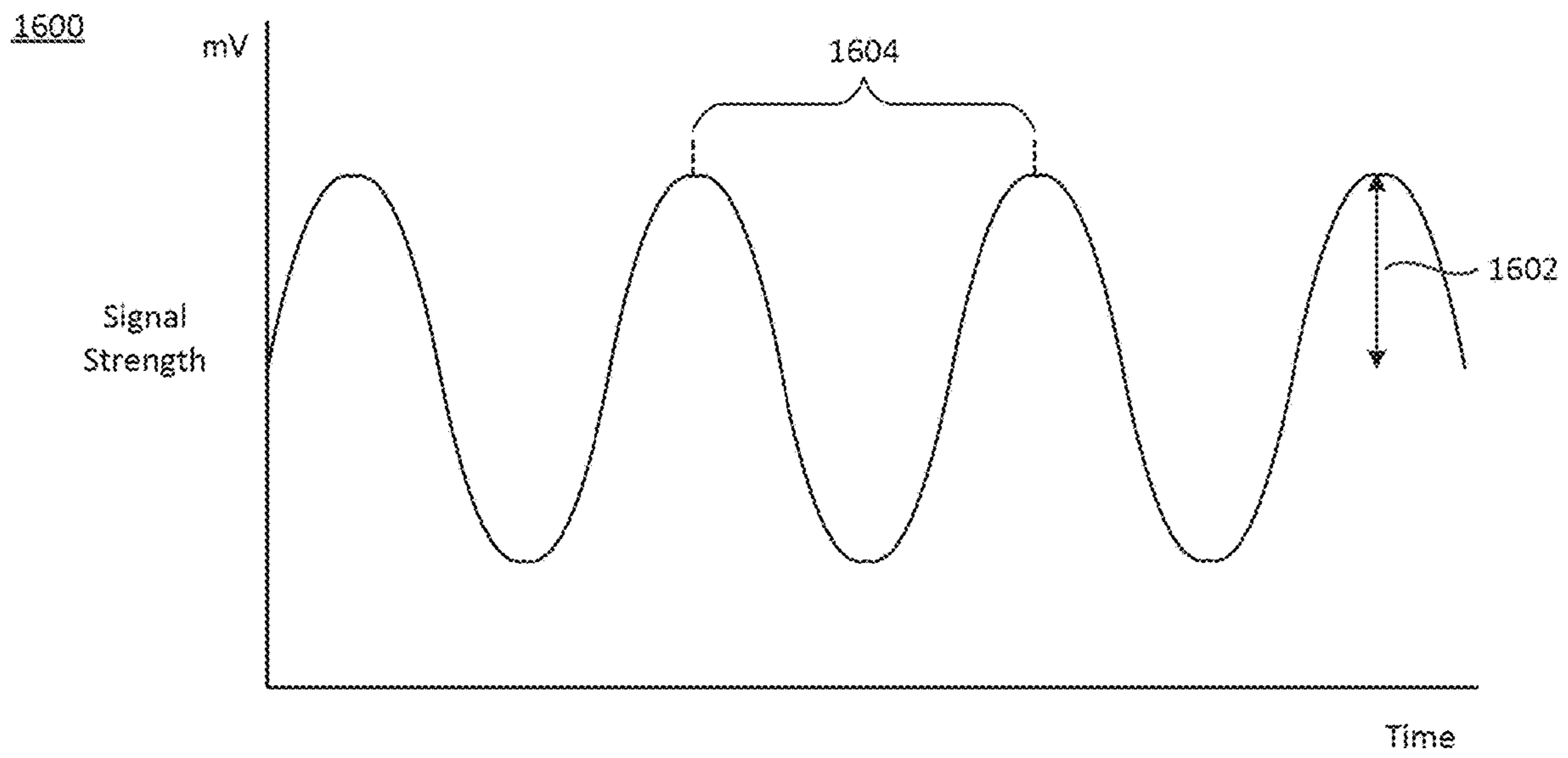


FIG. 17A

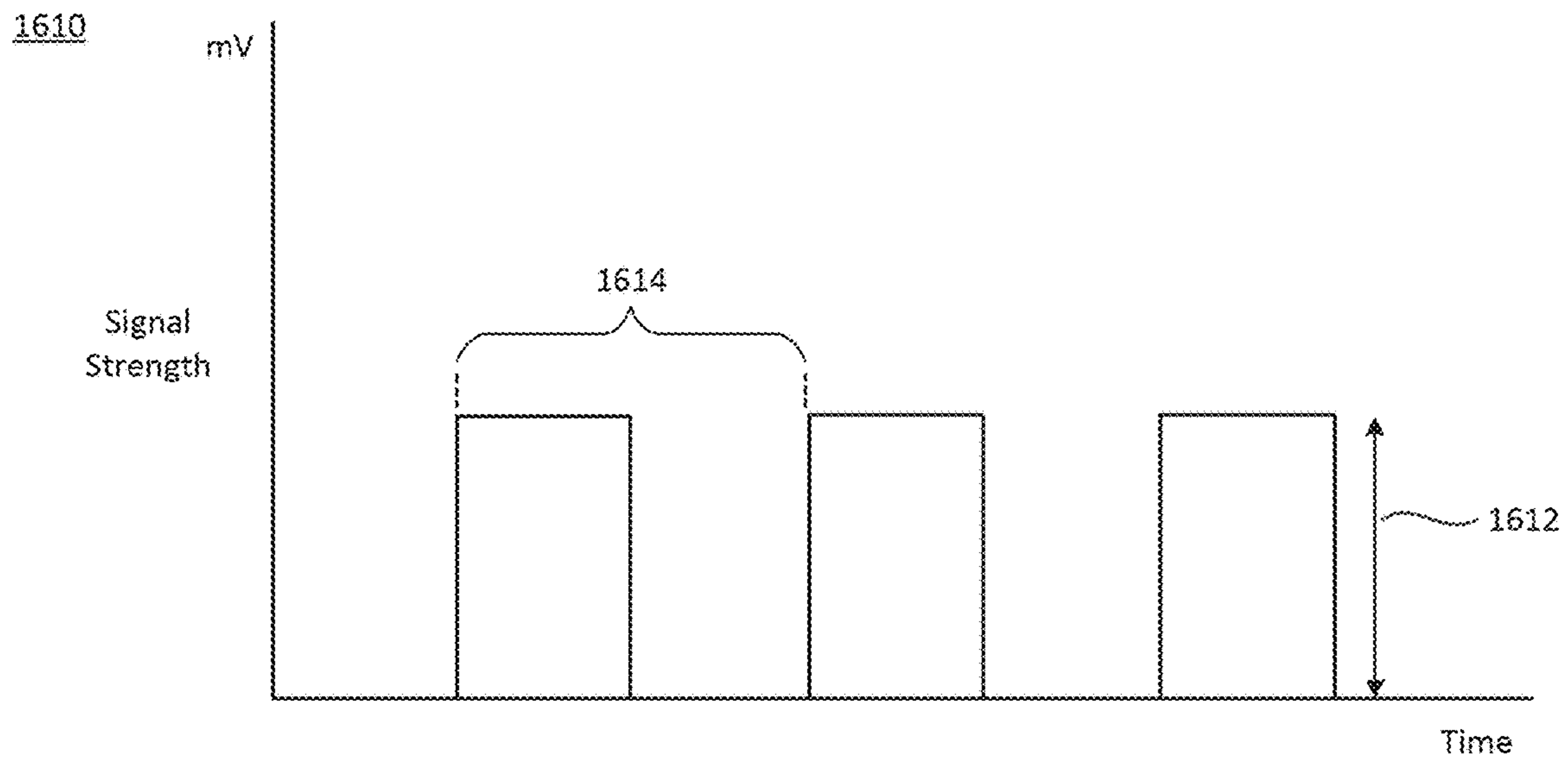


FIG. 17B

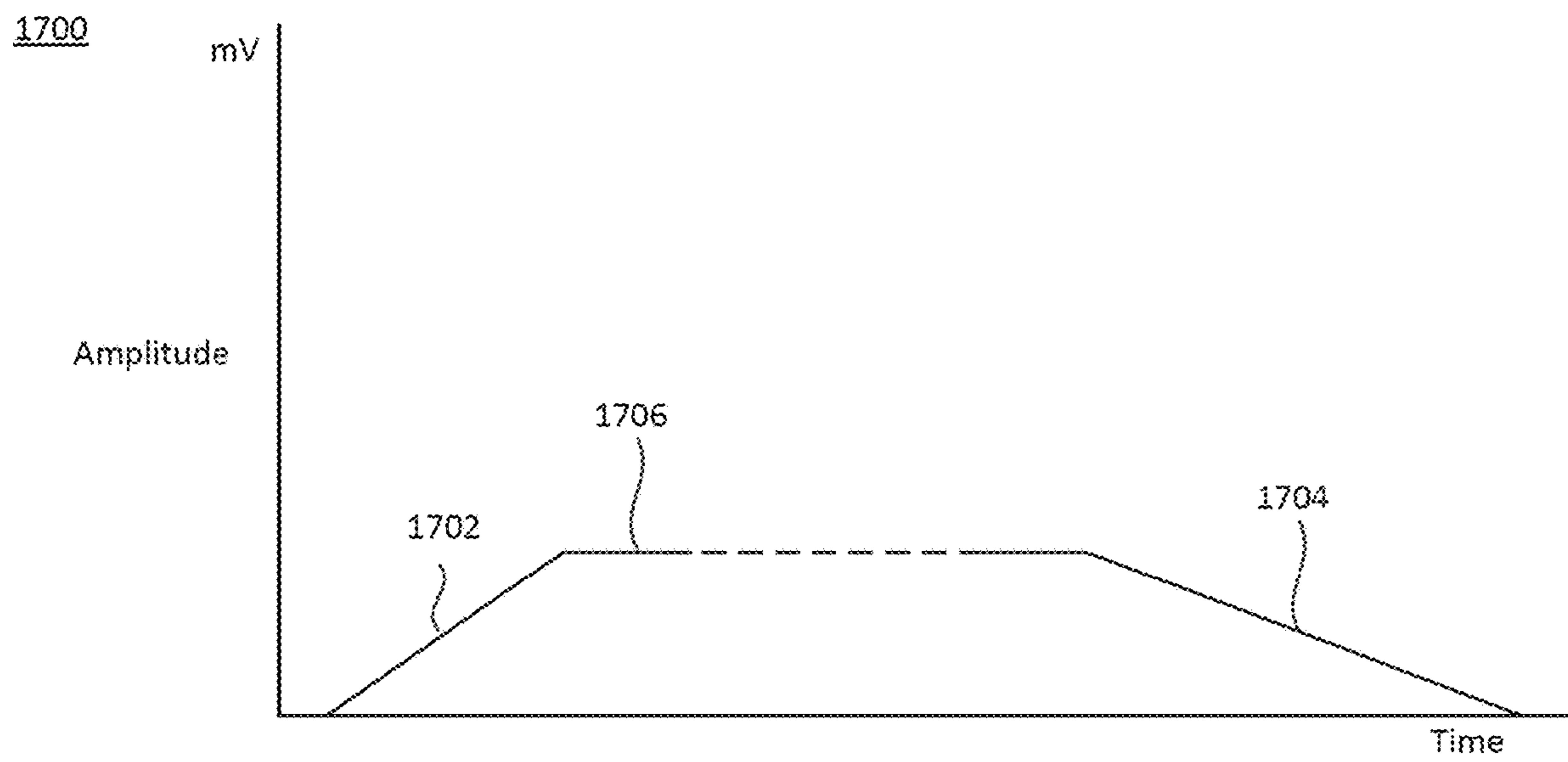


FIG. 18

1800

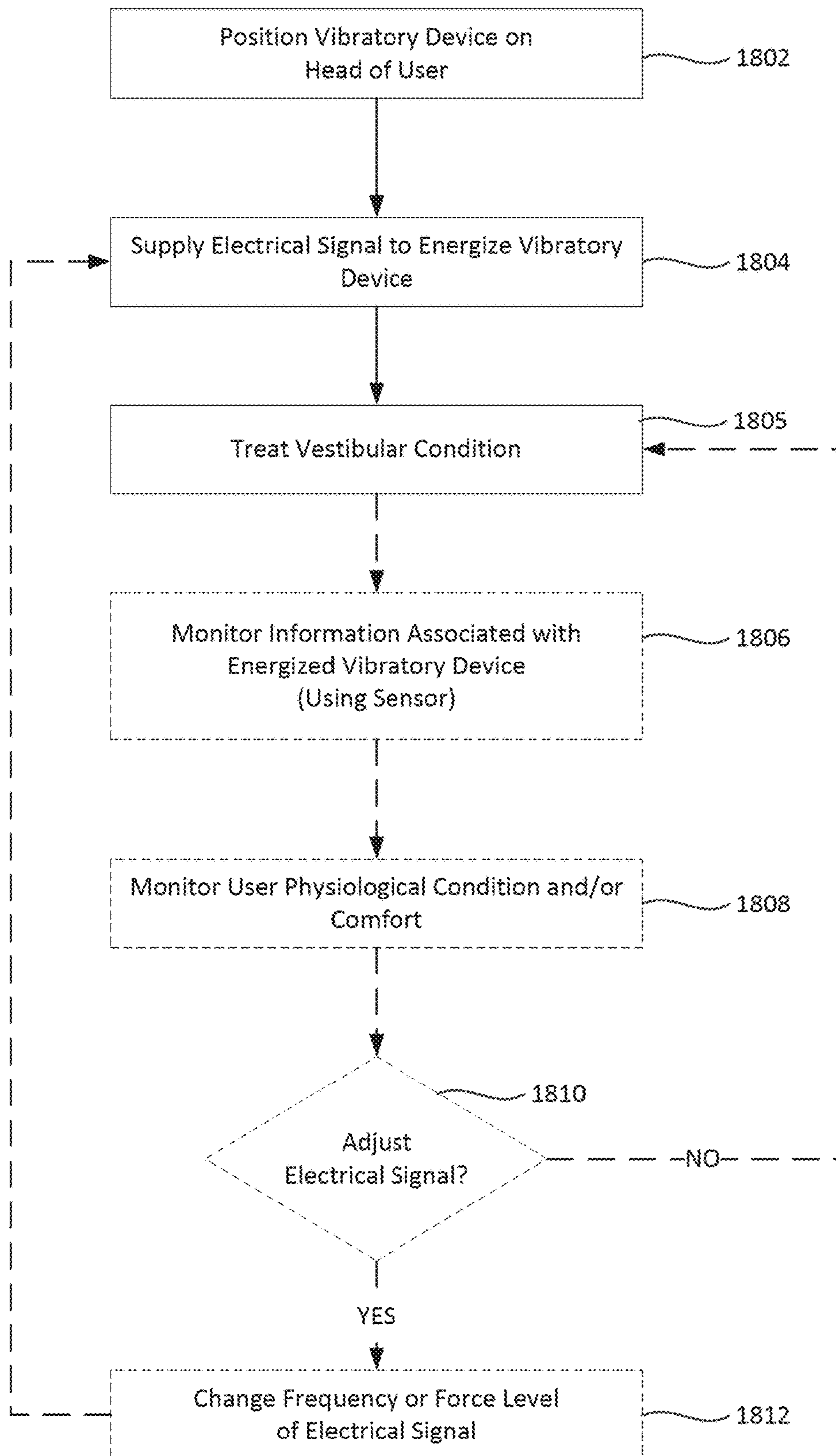


FIG. 19



1900

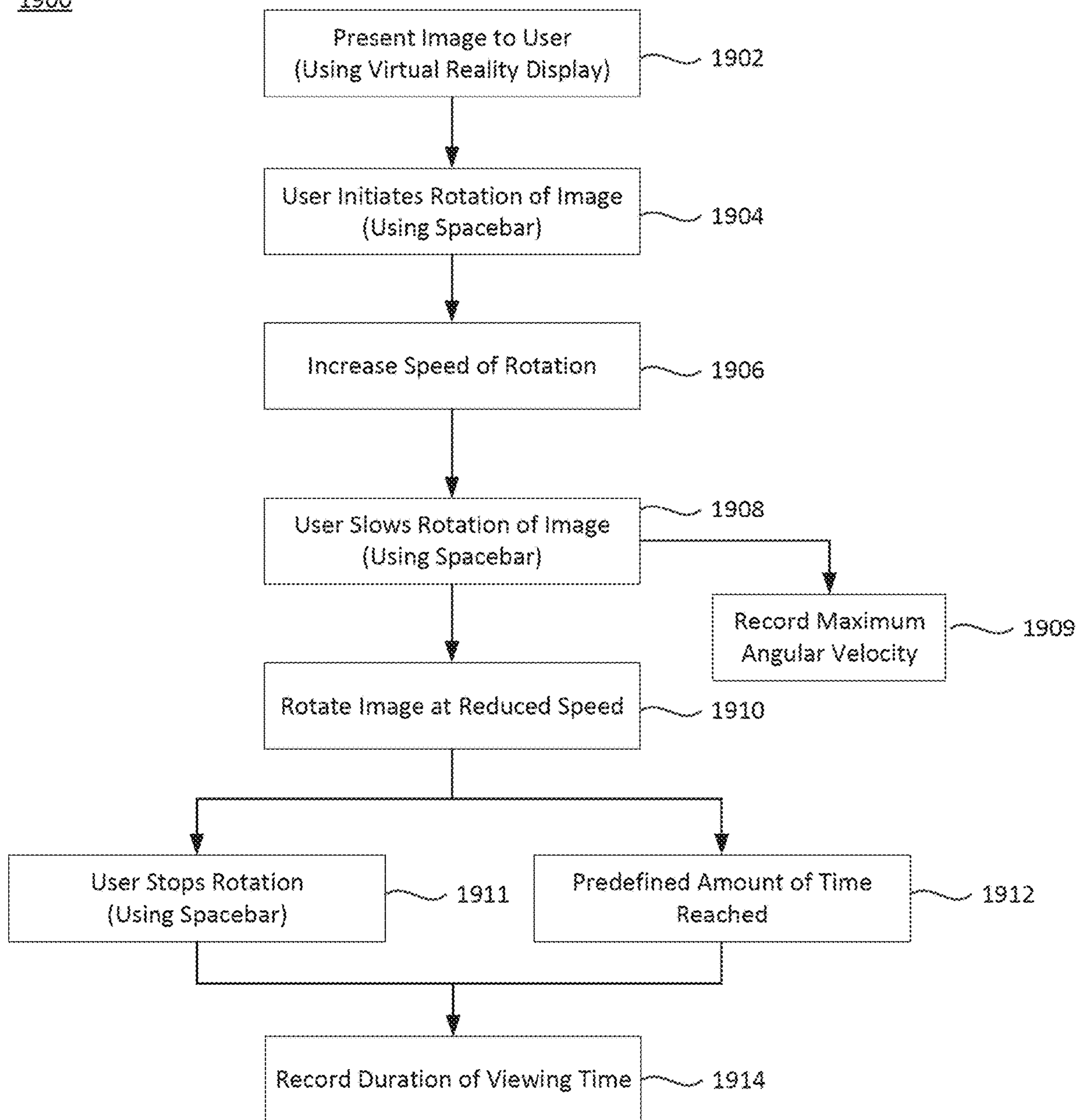


FIG. 20A

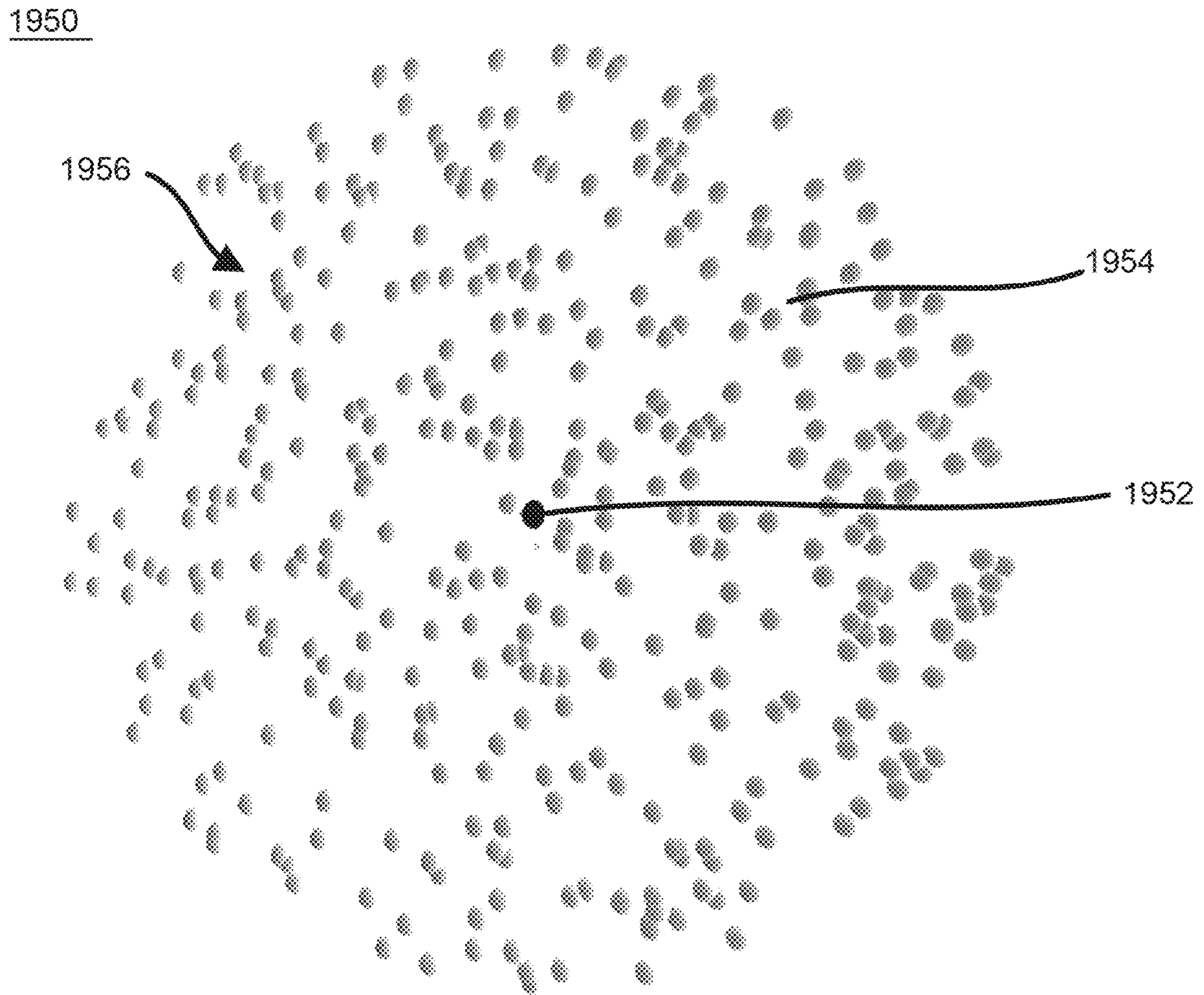


FIG. 20B

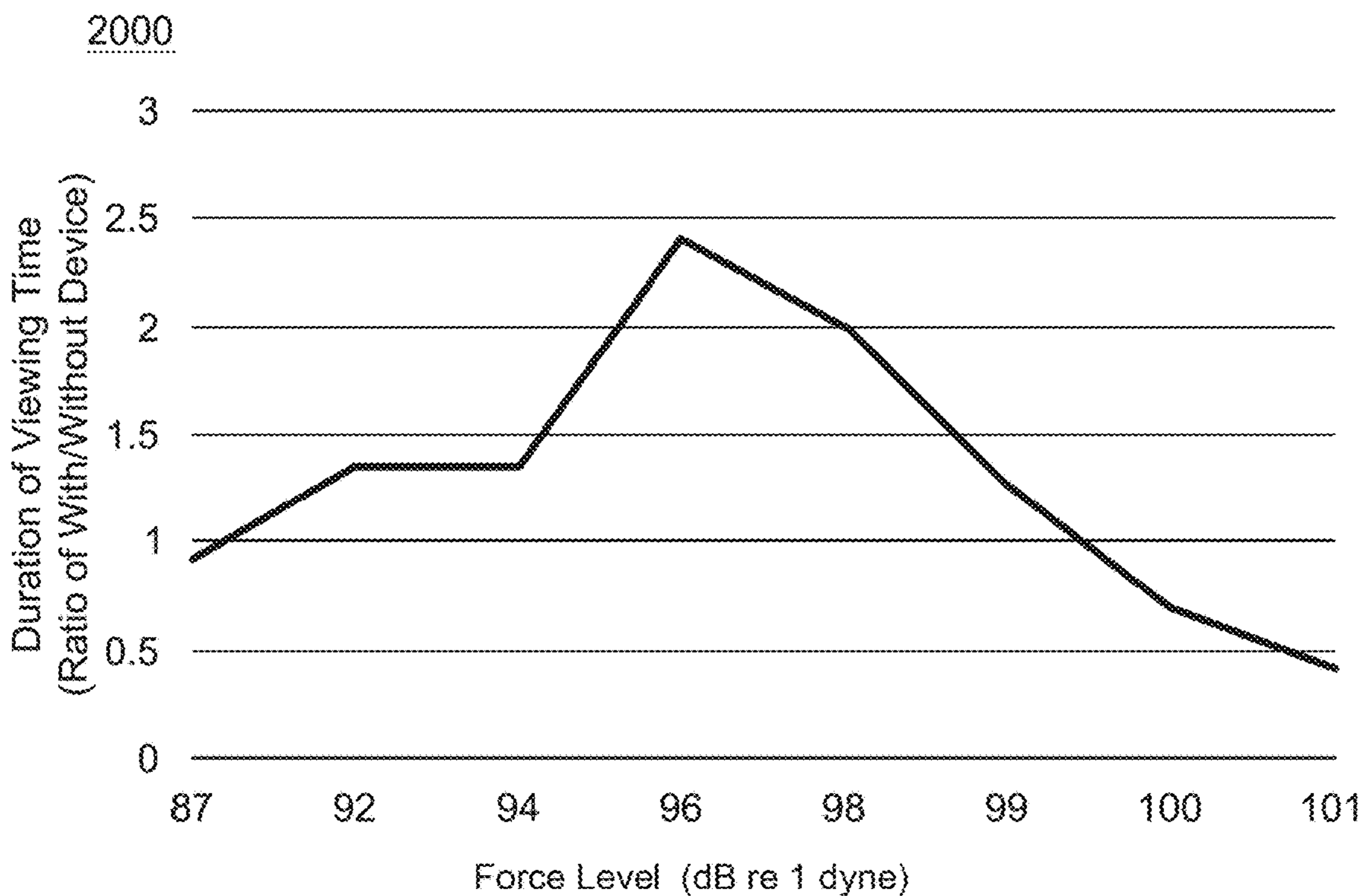


FIG. 21A

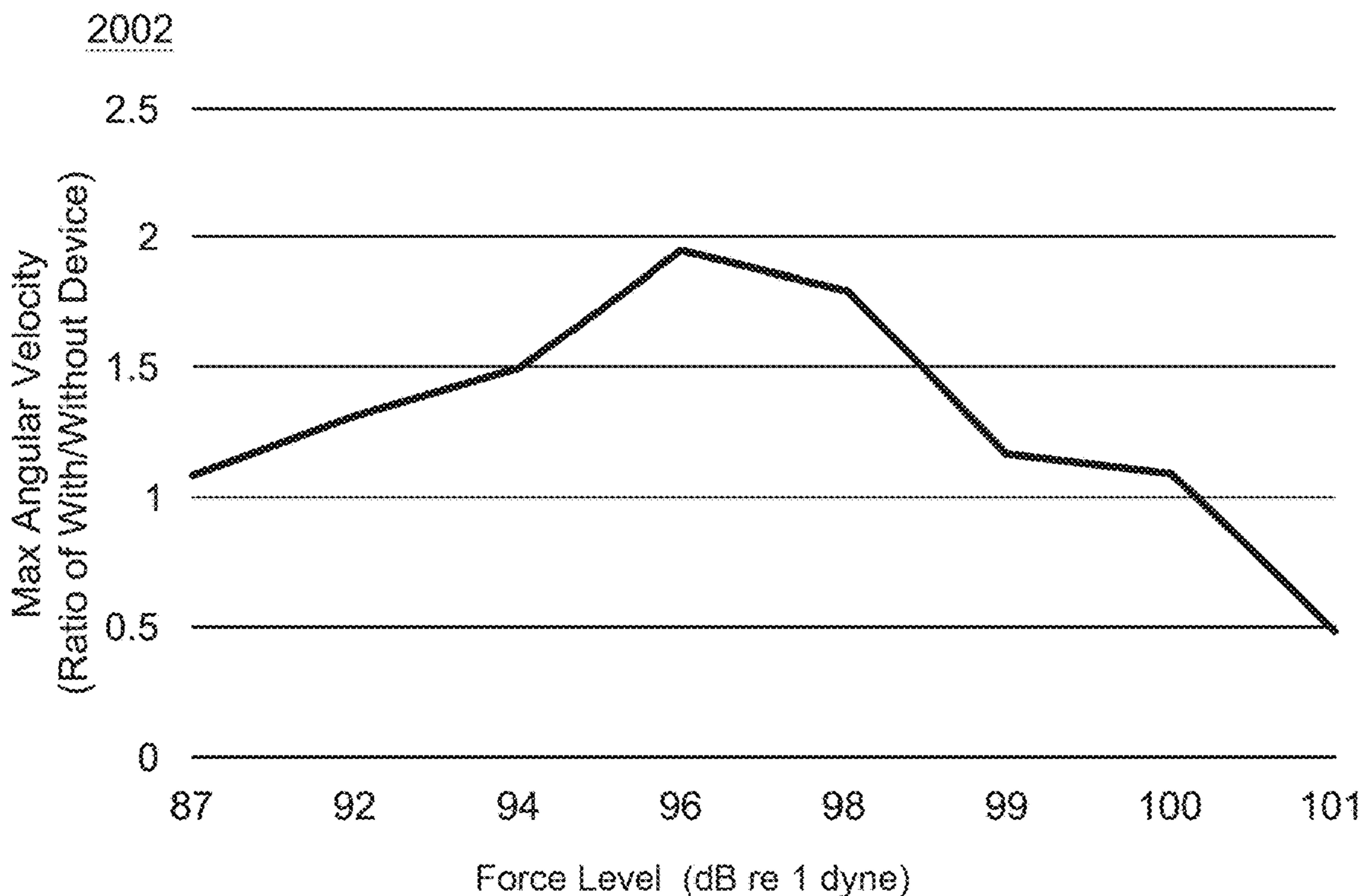


FIG. 21B

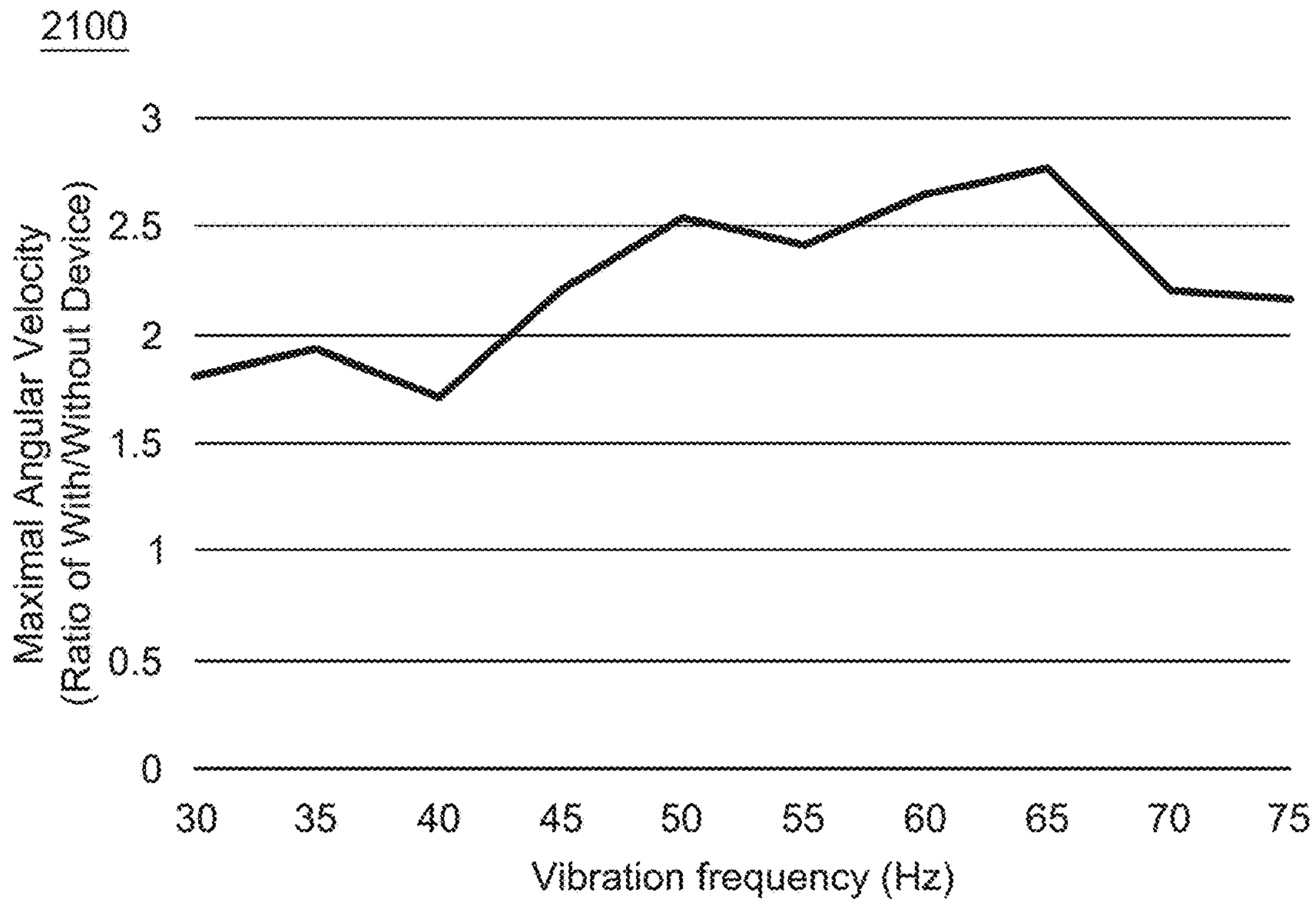


FIG. 22A

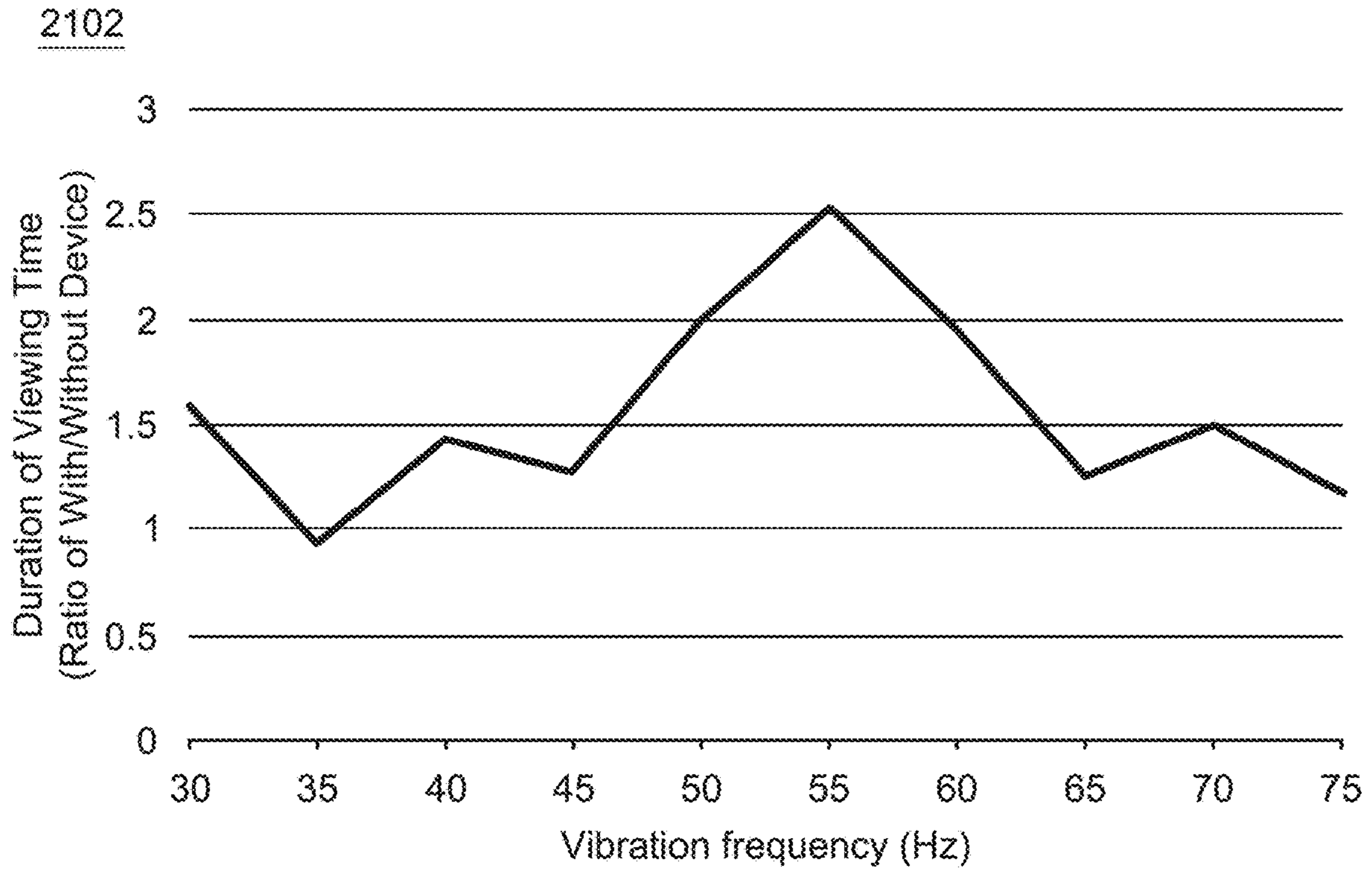


FIG. 22B

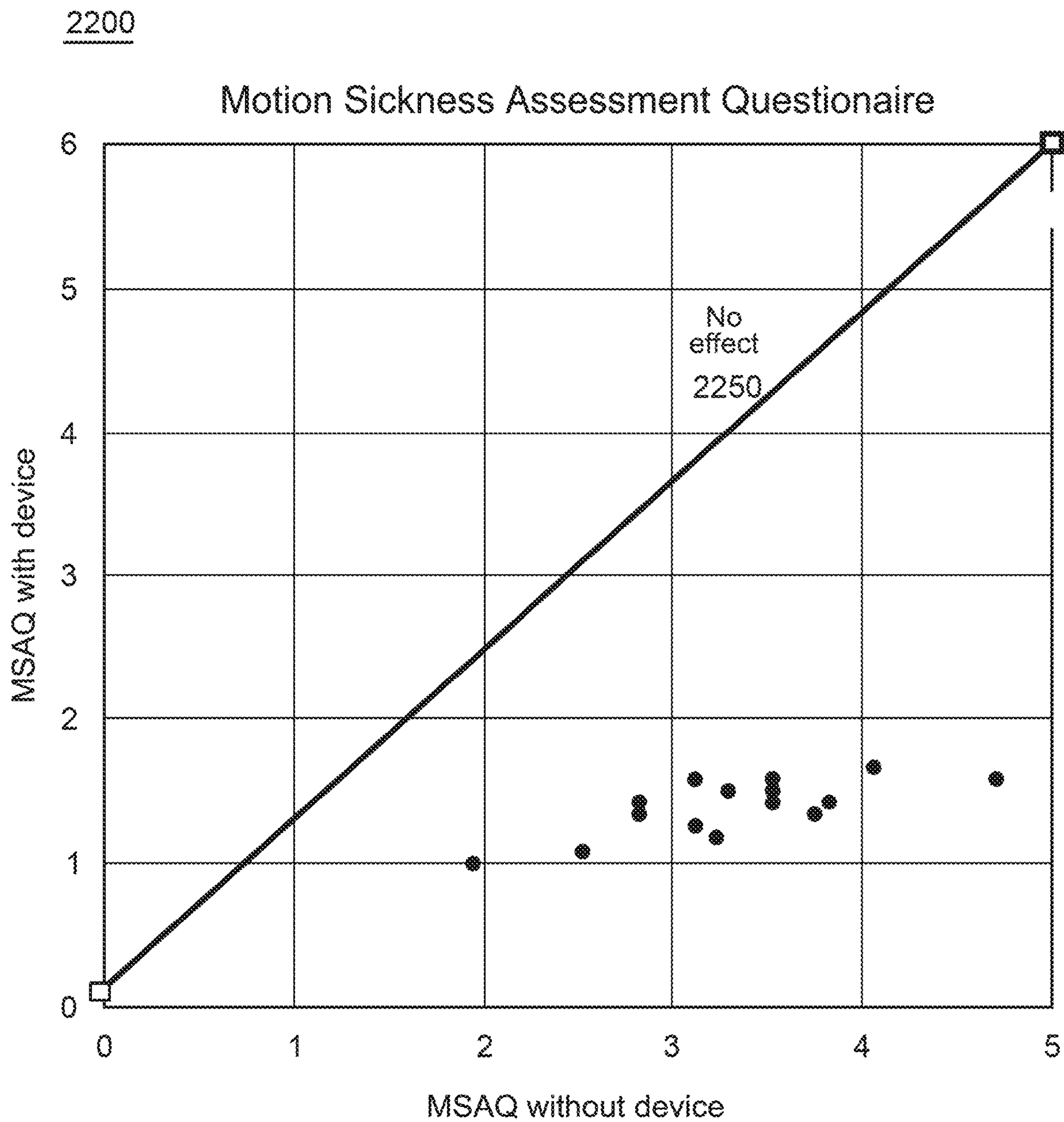


FIG. 23A

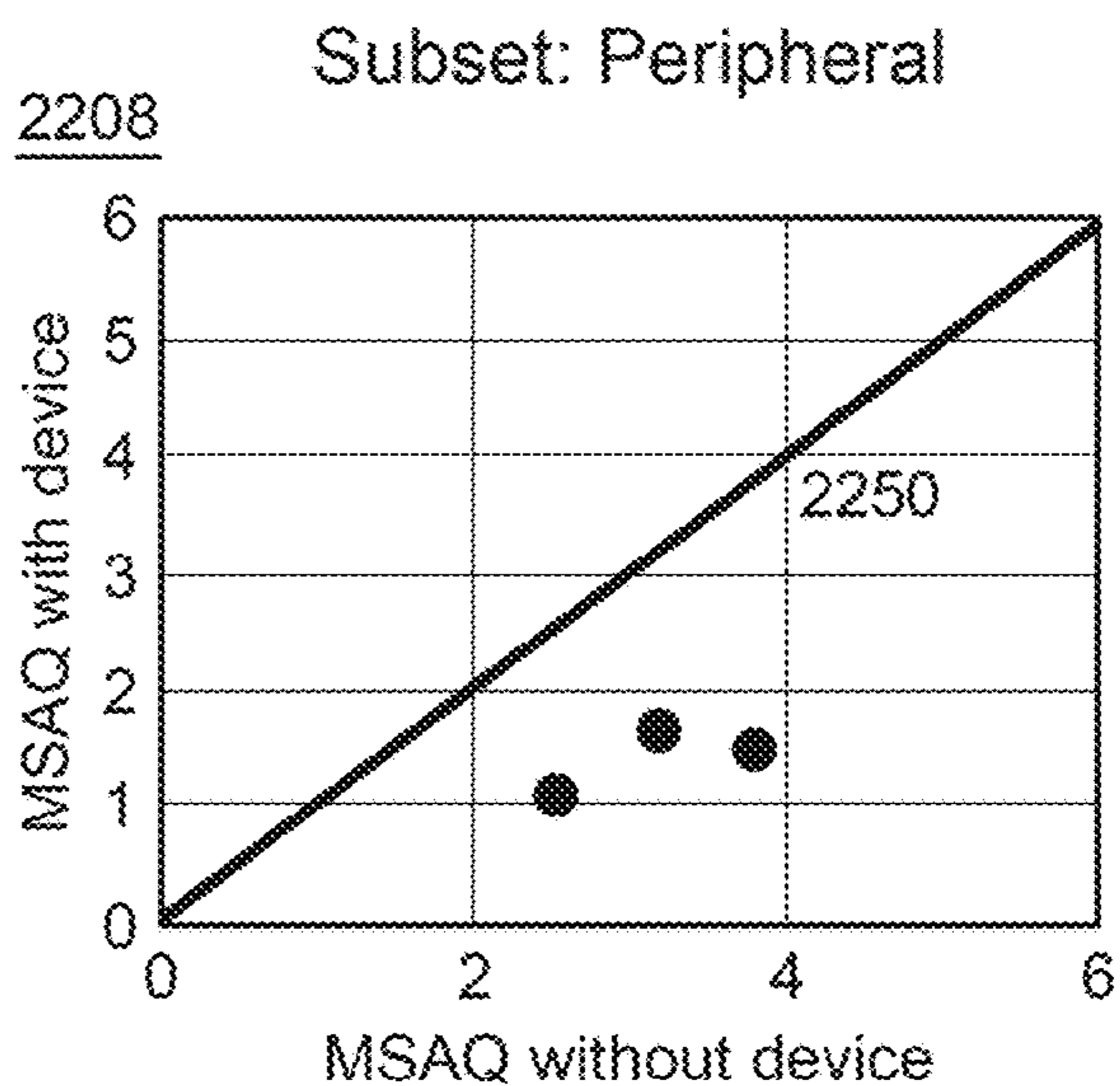
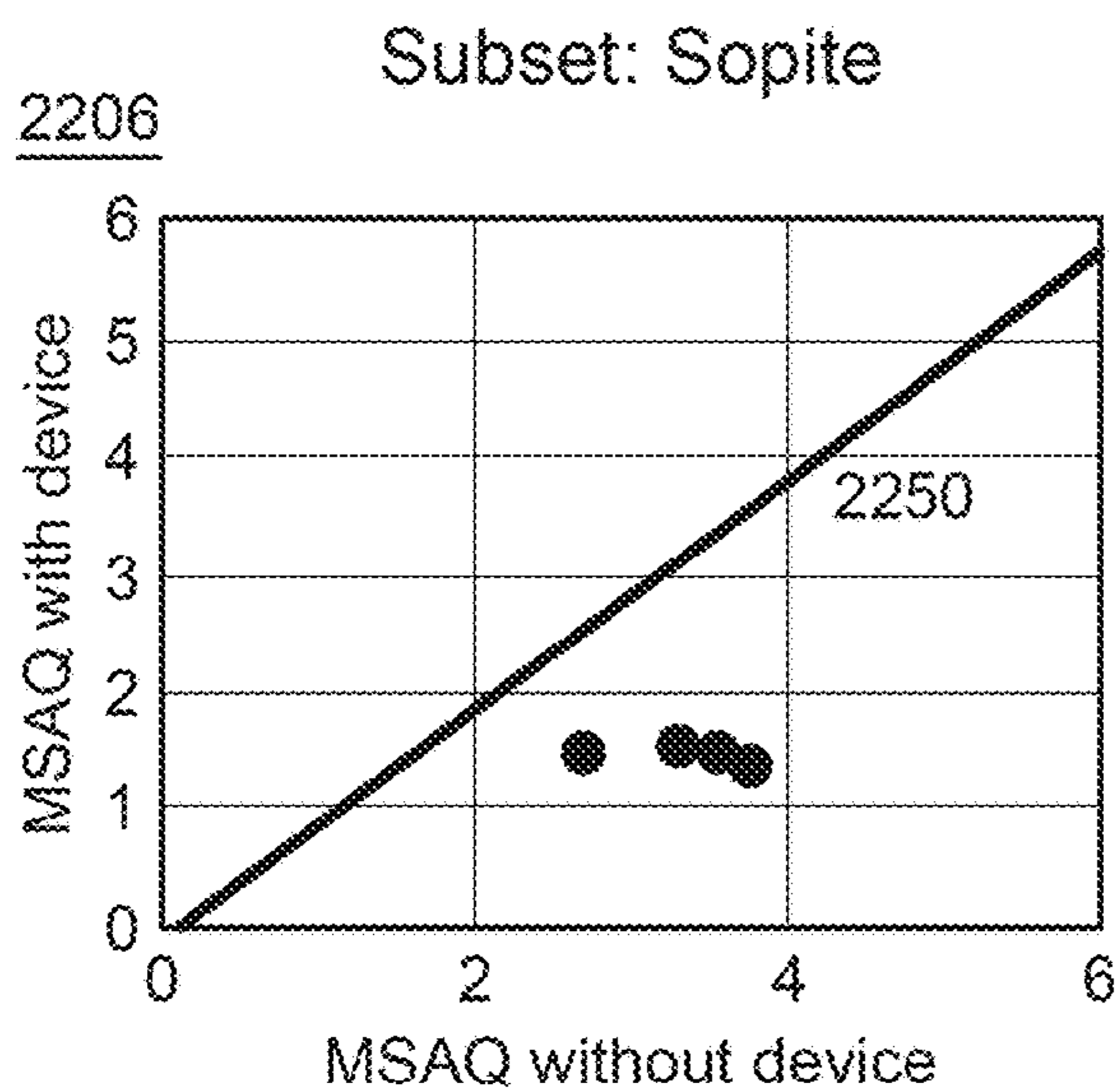
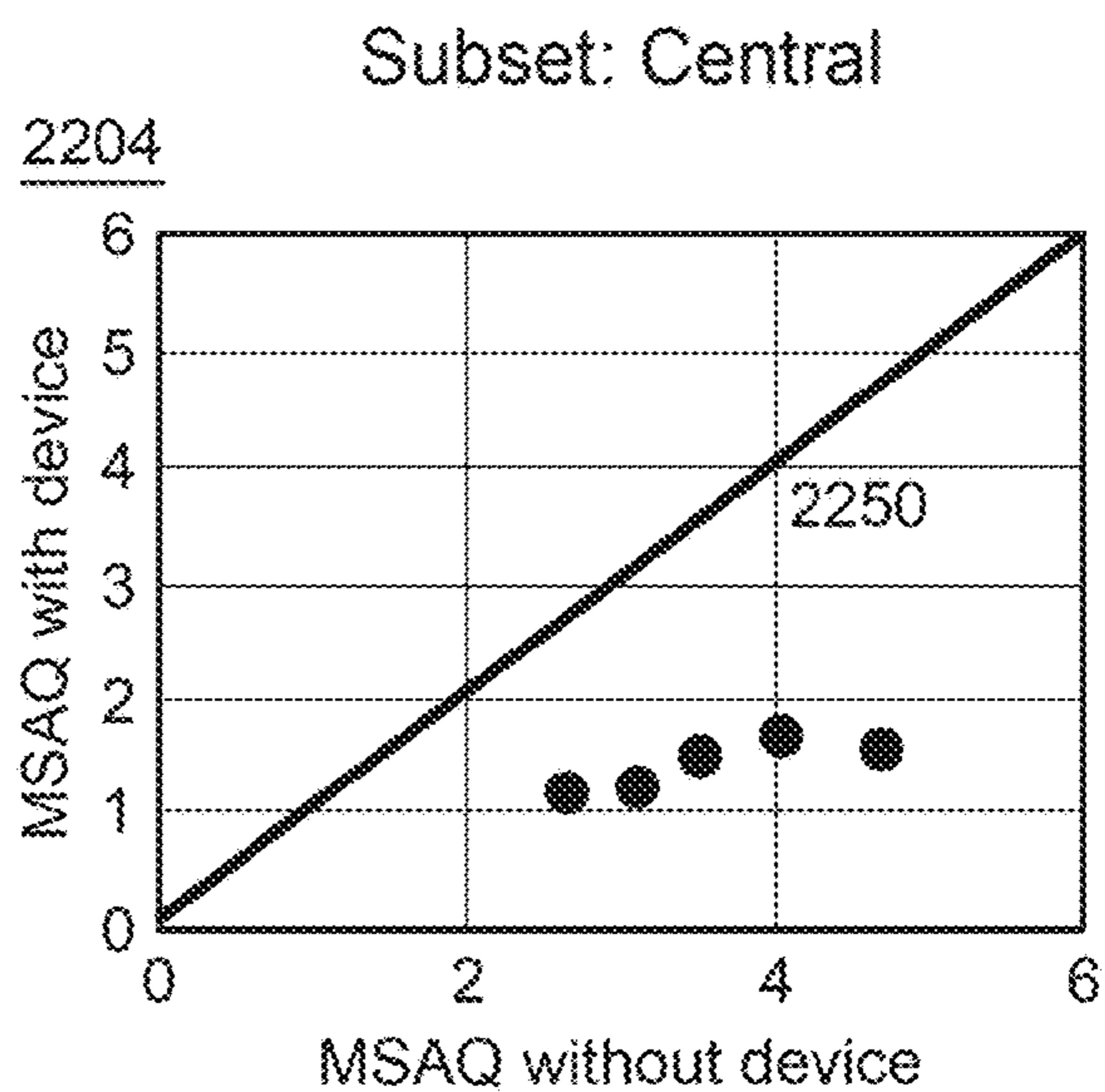
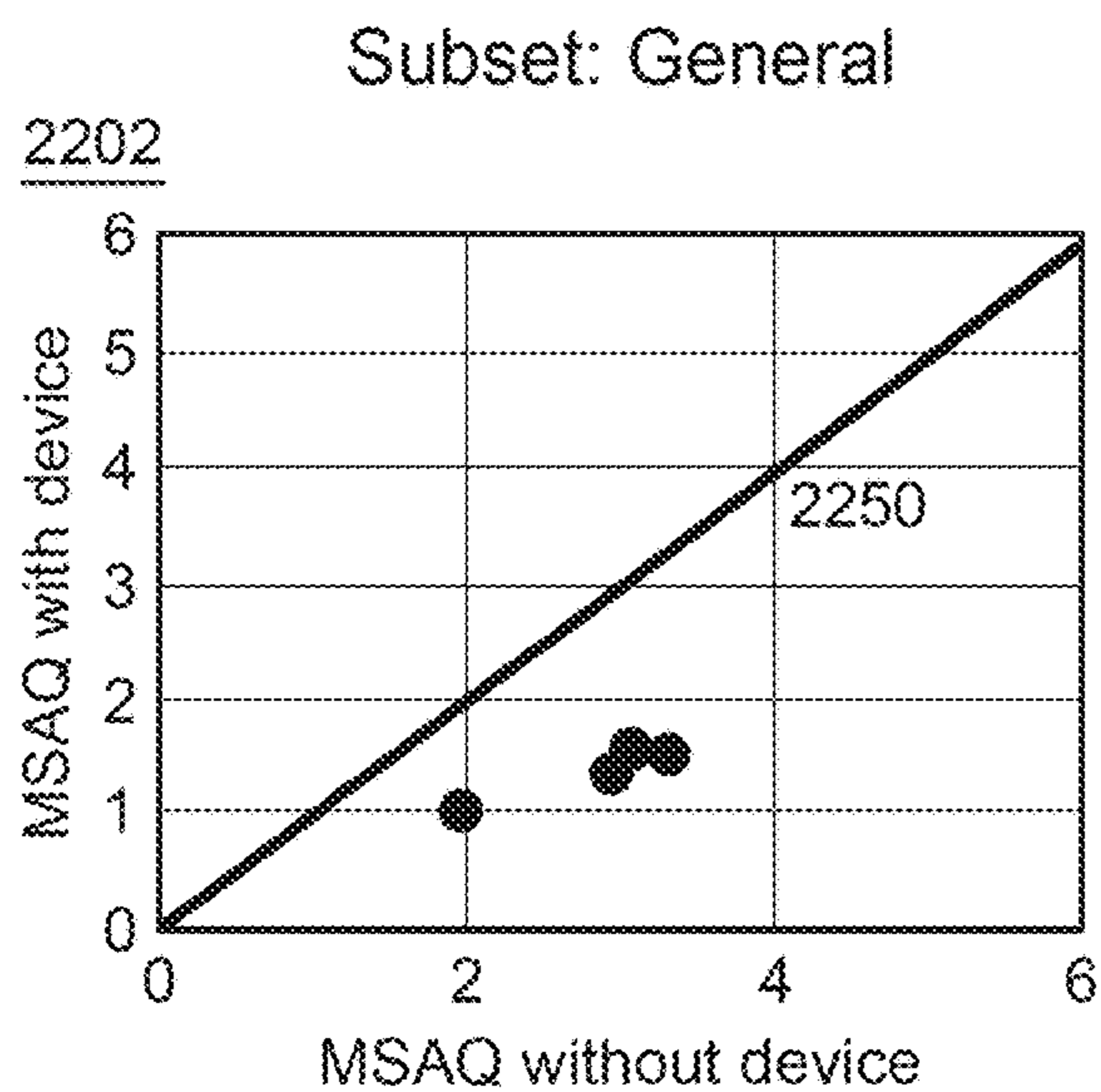


FIG. 23B

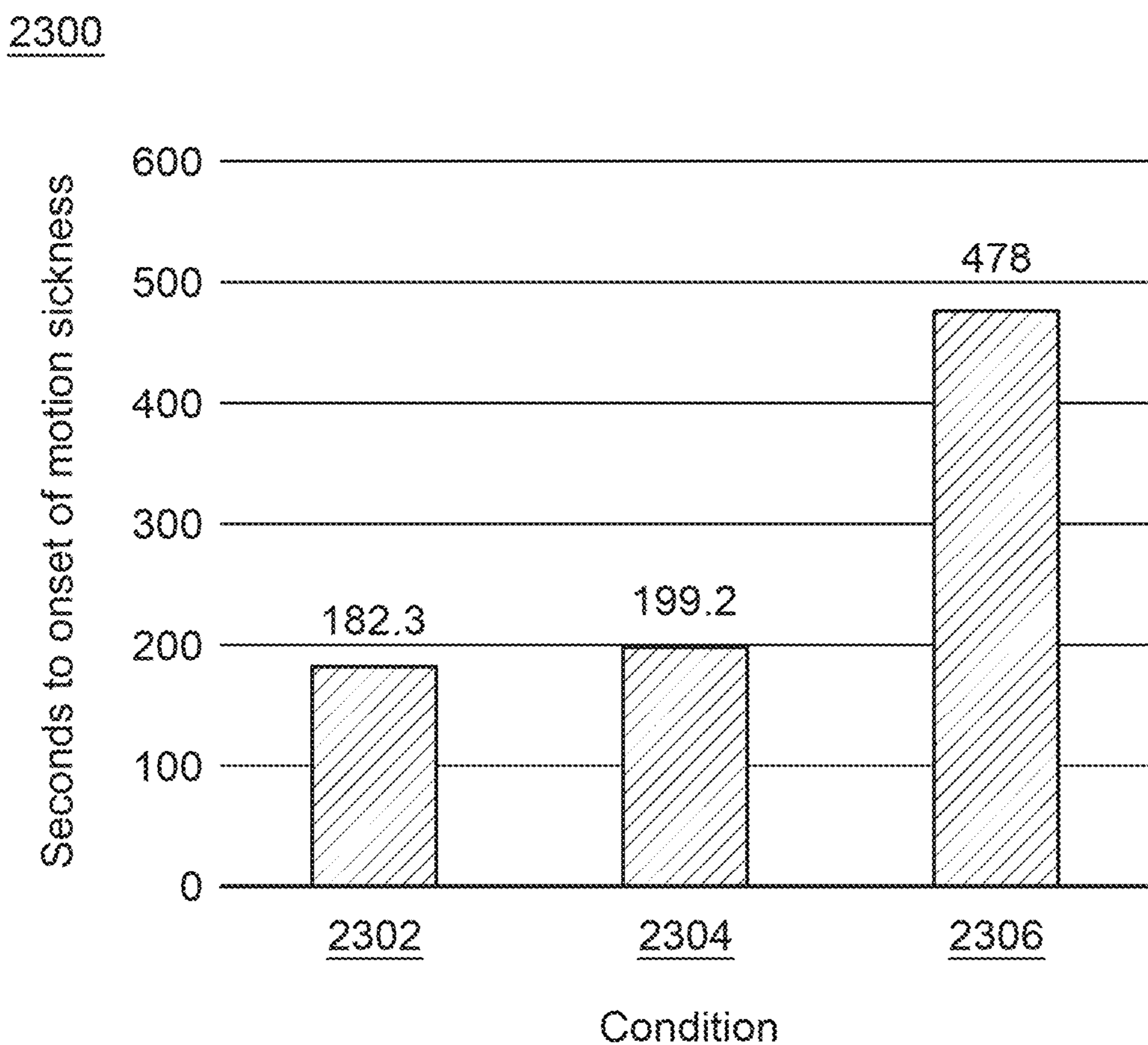


FIG. 24

## SYSTEMS, DEVICES, AND METHODS FOR TREATING VESTIBULAR CONDITIONS

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 15/982,867, filed May 17, 2018, entitled “Systems, Devices, and Methods for Treating Vestibular Conditions” (“the ’867 application”), which is a continuation-in-part of U.S. patent application Ser. No. 15/481,457, filed Apr. 7, 2017, entitled “Devices and Methods for Reducing the Symptoms of Maladies of the Vestibular System” (“the ’457 application”), which in turn claims priority to U.S. Provisional Application No. 62/421,708, filed Nov. 14, 2016, entitled “Devices and Methods for Treating Motion Sickness” (“the ’708 application”). The ’867 application also claims priority to and the benefit of U.S. Provisional Patent Application No. 62/629,197, filed Feb. 12, 2018, entitled “Methods and Devices for Treating the Proprioceptive Vestibular System,” and U.S. Provisional Patent Application No. 62/629,213, filed Feb. 12, 2018, entitled “Methods and Devices for Reducing Motion Sickness in Virtual Reality and Travel Applications.”

The disclosures of each of the above applications are incorporated herein by reference in their entirety.

### FIELD OF INVENTION

Disclosed embodiments relate to systems, devices, and methods for treating conditions such as, for example, motion sickness, dizziness, vertigo, migraines, and loss of consciousness, associated with a vestibular system of a subject. More specifically, the present disclosure relates to devices capable of generating vibratory signals that can affect a subject’s vestibular system.

### BACKGROUND

Orientation, balance, position, and movement of a body can be determined by the brain through a combination of signals received from various parts of anatomy, including eyes, ears, and muscles. For example, the vestibular system, in most mammals, is the sensory system that predominantly contributes sensory information related to balance and spatial orientation. The vestibular system of a subject is found in the inner ear of the subject, as shown in FIG. 1A, in a system of interconnected compartments forming the vestibular labyrinth.

FIG. 1A illustrates a portion of the anatomy of a subject 100, showing the vestibular system with respect to an external ear 110, portions of a skull 114, and bony portion of an ear 116, an ear canal 111, an ear drum 112, and the bones of a middle ear 113. The vestibular system includes semi-circular canals 122, 124, and 126, and otolith organs 128 and 130, housed within a vestibule 121 in the bony labyrinth of the inner ear, and is continuous with a cochlea 120. FIG. 1B provides a more detailed illustration of the vestibular system shown in FIG. 1A, depicting the vestibule 121 to include a utricle 128 and a saccule 130.

The three semi-circular canals 122, 124, and 126 are each oriented in a plane along one of three directions in which the head can rotate or move and detect motion in that direction, the directions being nodding up-down, shaking left-right, and tilting left-right. The otolith organs within the vestibule of the inner ear 121 detect gravitational forces and acceleration in the forward and backward directions. The otolith

organs include the utricle 128 that detects movements in the horizontal plane and the saccule 130 that detects movements in the vertical plane. The semi-circular canals 122, 124, and 126, and the otolith organs 128 and 130 are filled with endolymph, a fluid that moves with the movement of the head or body.

The movement of endolymph in the vestibular system of the inner ear can be sensed by nerve cells with hair bundles to determine movement and orientation of the head. Portions called ampula in the semi-circular canals and macula in the otolith organs include hair cells, which function as the sensory receptors of the vestibular system and include hair bundles or stereocilia that detect and transduce movement of the endolymph into signals of body movement and report the signals to the brain. The otolith organs also include a layer of crystals of calcium carbonate called otoconia or otoliths that shift in response to changes in acceleration (e.g., changes in motion or orientation with respect to gravity) leading to movement in the layers below the otoconia and the movement of hair bundles. Additionally, otoliths sink in the direction of gravity and pull on bundles of hair cells to aid in distinguishing directions, e.g., up from down.

FIGS. 2A and 2B provide detailed views of the anatomy of the macula in the otolith organs (e.g., the utricle 128 and the saccule 130 shown in FIG. 1B) and the sensory receptors, in an upright state and in a state of movement, respectively. FIG. 2A shows the macula including an otolithic membrane 132 and a cellular layer including hair cells 134 and supporting cells 136. The hair cells 134 include hair like projections or stereocilia 132 that extend into one or more gelatinous layers. The organization of the macula also includes a layer of otoconia or otoliths 138 that shift in response to movement in the endolymph and/or to acceleration of the body. FIG. 2A shows the hair cells 134 and the otoliths 138 in an upright configuration, and FIG. 2B shows the hair cells 134 and the otoliths 138 in a displaced or angled configuration when a directional force 140 (e.g. gravity) acts on the otoliths 138. Similarly, movement of the endolymph within the semi-circular canals 122, 124, and 126, can result in movement of the hair cells within the ampula of the semi-circular canals (not shown) perceiving and signaling relative movement of the body and/or head (e.g., angular acceleration of the head).

In addition to signals from the vestibular system, horizontal and vertical visual patterns received by the eyes can affect perception of orientation, balance, and position; and differential strain on opposing neck muscles can affect perception of head position and orientation. When signals from these sources do not match, an individual can develop motion sickness, experience vertigo, dizziness, vestibular migraines, unconsciousness, or other conditions. Unmatched orientation, balance, position and movement signals can be the result of extreme or unfamiliar movement during, for example, travel in cars, trains, airplanes, and other modes of transportation. Unmatched signals may also result from simulated perceived movement during, for example, three dimensional (3D) movies, 3D video games, and virtual reality devices. Therefore, it can be desirable to have a device for treating various vestibular conditions that may result from unmatched signals being received from a subject’s vestibular system, eyes, or other anatomy.

### SUMMARY

Apparatus and methods described herein can include a vibratory device configured to apply a vibratory signal to a portion of a head of a user such that the vibratory signal can



be conducted via bone to a vestibular system of the user and cause a portion of the vestibular system to move in a manner equivalent to that of a therapeutically effective vibratory signal applied to an area overlaying a mastoid bone of the user. The therapeutically effective vibratory signal can (1) have a frequency less than 200 Hz and a force level between 90 and 100 dB re 1 dyne and (2) being therapeutically effective to treat a physiological condition associated with the vestibular system.

Apparatus and methods are described herein can, in some embodiments, include a vibratory device configured to apply a set of vibratory signals to a portion of a head of a user such that the set of vibratory signals can be conducted via bone to a vestibular system of the user to treat a physiological condition associated with the vestibular system. The vibratory device can be associated with a set of resonant frequencies including a lowest resonant frequency that is less than 200 Hz. The set of vibratory signals can collectively have an amount of power at the lowest resonant frequency that is greater than an amount of power at remaining resonant frequencies from the set of resonant frequencies.

In some embodiments, apparatus described herein can include a vibrating element configured to apply a vibratory signal to a portion of a head of a user such that the vibratory signal can be conducted via bone to a vestibular system of the user to treat a physiological condition associated with the vestibular system. The vibrating element can be configured to include a housing defining a chamber, a magnet movable within the chamber to produce the vibratory signal, a suspension element configured to suspend the magnet at a position within the chamber, and a coil configured to generate a magnetic field to cause the magnet to move about the position.

Methods disclosed herein include positioning a vibratory device over an area of a head of a user, and energizing the vibratory device, after the positioning, to apply a vibratory signal to the area such that the vibratory signal can be conducted via bone to a vestibular system of the user. The vibratory signal can be configured to cause a portion of the vestibular system to move in a manner equivalent to that of a vibratory signal (1) applied to an area overlaying a mastoid bone of the user and having (2) a frequency less than 200 Hz and a force level between 90 and 100 dB re 1 dyne. The methods can further include treating, in response to energizing the vibratory device, a physiological condition associated with the vestibular system.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A illustrates an anatomy of a subject, including a bony labyrinth of an inner ear housing a vestibular system.

FIG. 1B provides a detailed illustration of the vestibular system and the cochlea, within the bony labyrinth of FIG. 1A.

FIGS. 2A and 2B are illustrations of a portion of a macula of the otolith organs shown in FIG. 1B, in an upright state and in a state of experiencing a directional force, respectively.

FIG. 3 is a schematic illustration of a placement of a vibratory device to apply vibratory signals to the vestibular system, according to an embodiment.

FIG. 4A is a schematic illustration of an example system for treating symptoms associated with vestibular conditions, according to an embodiment.

FIG. 4B is a schematic illustration of an example system for treating symptoms associated with vestibular conditions, according to another embodiment.

FIG. 5 is a schematic illustration of an example vibratory device of a system for treating symptoms associated with vestibular conditions, according to an embodiment.

FIG. 6 is a schematic illustration of a cut-away view of an example vibratory device of a system for treating symptoms associated with vestibular conditions, according to another embodiment.

FIG. 7A is a schematic illustration of a cross-sectional view of a vibratory device in a system for treating symptoms associated with vestibular conditions, according to an embodiment.

FIG. 7B is a schematic illustration of a cross-sectional view of the vibratory device in FIG. 7A integrated into a physical platform for placement on a subject, according to an embodiment.

FIG. 8 is a schematic illustration of a cross-sectional view of a vibratory device in a system for treating symptoms associated with vestibular conditions, according to another embodiment.

FIG. 9A is a perspective view of a spring as a suspension element of a vibratory device in a system for treating symptoms associated with vestibular conditions, according to an embodiment.

FIGS. 9B and 9C are illustrations of a top view and a bottom view, respectively, of the spring in FIG. 9A.

FIGS. 10-15 are schematic illustrations of example vibratory devices including and/or integrated into different support elements, according to various embodiments.

FIG. 16 is a schematic illustration of a human skull, indicating example locations for the placement of a vibratory device in a system for treating symptoms associated with vestibular conditions, according to various embodiments.

FIGS. 17A and 17B depict two example waveforms that can be used to energize a vibratory device in a system for treating symptoms associated with vestibular conditions, according to various embodiments.

FIG. 18 illustrates an example energizing profile that can be used to energize a vibratory device in a system for treating symptoms associated with vestibular conditions, according to an embodiment.

FIG. 19 is a flowchart of an example method for using a vibratory device to treat symptoms associated with vestibular conditions.

FIG. 20A is a flowchart of a procedure of a study that was conducted to test a vibratory device for treating symptoms associated with vestibular conditions.

FIG. 20B is a schematic illustration of a static view of an example visual stimulus used in the procedure depicted in FIG. 20A to test the vibratory device.

FIGS. 21A and 21B depict results from the study procedure depicted in FIG. 20A for testing the vibratory device at different force levels.

FIGS. 22A and 22B depict results from the study procedure depicted in FIG. 20A for testing a vibratory device at different frequencies.

FIGS. 23A and 23B depict data associated with a questionnaire completed by subjects of a study conducted to test a vibratory device for treating symptoms associated with vestibular conditions, using a test procedure, in yet another instance.

FIG. 24 depicts results from a study conducted to test a vibratory device for treating symptoms associated with vestibular conditions, using a test procedure, in yet another instance.

#### DETAILED DESCRIPTION

Apparatus and methods are described herein for treating vestibular conditions by using a vibratory device capable of

generating vibratory signals and applying the vibratory signals via bone conduction to a vestibular system of a subject such that the vibratory signals can disrupt an anatomy of the subject's vestibular system.

As described above, sensory signals from a vestibular system of a subject aid in the perception of orientation, balance, position, and movement of a body of the subject. In addition to signals from the vestibular system, other sensory modalities, such as visual signals from the eyes, can affect perceptions of orientation, balance, and position; and differential strain on opposing neck muscles can affect perceptions of head position and orientation. When signals from these various sensory sources such as the vestibular system, the visual system, and the proprioceptive system do not match, an individual can develop conditions like motion sickness, vertigo, dizziness, vestibular migraines, unconsciousness, or other conditions. For example, unmatched orientation, balance, position, and movement signals can result from extreme or unfamiliar movement during, for example, travel in cars, trains, airplanes, and other modes of transportation, or result from experiencing virtual or augmented 3D environments such as 3D movies, 3D video games, virtual reality devices, etc.

In a natural adaptive response, a brain can ignore sensory information in signals that are chaotic, repetitive or not novel, or unintelligible. For example, it has been shown that vibrations from sound can affect the vestibular organs in the inner ear and decrease response (e.g., an amplitude of electrical signals) in the cerebellum. See H. Sohmer et al., "Effect of noise on the vestibular system—Vestibular evoked potential studies in rats," 2 Noise Health 41 (1999). Nonetheless, the same studies have shown that very high intensities are required in order for sound to affect the vestibular system. Thus, traditional headphones, earphones, and speakers, used to produce sound from generating vibratory signals in the air, are limited in their ability to treat symptoms like motion sickness response, vertigo, vestibular migraines, and other physiological responses. Many of these technologies are not designed to deliver high intensity signals. Moreover, such high intensity signals may harm or disrupt human hearing.

As an alternative to using sound, mechanical vibrations can be used to affect the vestibular system to therapeutically treat various conditions. One technology that can be used to create mechanical vibrations is a surface or bone conduction transducer. Presently available bone conduction transducers, however, have certain drawbacks associated with treating symptoms or conditions of the vestibular system. For example, existing devices often have significant limitations, such as production of a significant amount of heat and/or audible noise, which can prevent their use in direct contact with a person's skin or in close proximity to a person's ear. Many existing devices are also large and bulky, which make them impractical for use under circumstances where the therapeutics effects are needed, such as, for example, during travel, while reading, while using a virtual reality device, etc.

Existing devices, such as a surface or bone conduction transducer, are inefficient at producing low frequency vibrations. Many produce vibratory signals at high frequencies that are audible and therefore distracting. Accordingly, when such devices are used close to a person's ear, the noise they create can be disruptive and irritating. Many existing devices produce high frequency vibrations in large part due to power being directed to higher, resonant frequencies instead of the lower, fundamental frequency of a vibratory signal being generated by such a transducer. Even when

designed to produce low frequency vibrations, existing bone conduction transducers may be inefficient because they produce a large spectrum of frequencies (e.g., frequencies at many harmonics) when the lower frequencies are the ones that are needed. Accordingly, disclosed systems and methods are directed to the treatment of symptoms associated with conditions of the vestibular system that do not produce a high level of heat or audible noise, and have high efficiency in delivering lower frequency vibratory signals, among other features.

FIG. 3 schematically illustrates the placement of a vibratory device 200 near an external ear 110 of a subject. The vibratory device 300 can be configured to apply vibratory signals 202 conducted via bone to treat one or more symptoms or conditions associated with the subject's vestibular system. A portion 204 of the vibratory signals 202 can be conducted via bone 116 to the bony labyrinth of the inner ear and to the vestibular system. For example, the portion 204 of the vibratory signals travels through the bone to the semicircular canals 122, 124, and 126 and the vestibule 121 housing the otolith organs, the utricle and the saccule.

The vibratory device 200 can be positioned such that vibratory signals can be applied to the vestibule 121 to cause the hair cells in the otolith organs in the vestibule 121 and the semicircular canals 122, 124, and 126 to move in a repetitive, chaotic, or noisy manner to reduce, mitigate, or treat symptoms associated with vestibular conditions. Some example vestibular conditions can include various types of motion sickness (e.g., sea sickness, air sickness, car and train sickness, sickness from exposure to virtual reality or simulators, sickness from experiences such as rides on a roller coaster, and effects of sopite syndrome), vertigo such as benign paroxysmal positional vertigo, nausea from a variety of causes (e.g., vestibular system testing including caloric electronystagmography (ENG)/videonystagmography (VNG) testing, head impulse testing, vestibular evoked myogenic potential (VEMP) testing such as cervical VEMP and ocular VEMP testing, functional gait assessment, etc., or arising from conditions such as chemotherapy, radiotherapy of a base of the skull, nausea related to pregnancy, nausea from alcohol or poison consumption, etc.), infection, vestibular neuritis, vestibular schwannoma, Meniere's disease, migraines, Mal de Debarquement syndrome, spatial discordance, sopite syndrome, etc.

The vibratory device 200 can also be positioned, as described herein, to provide vibratory signals conducted via bone to treat other conditions, including, for example, dizziness, loss of balance, etc. caused by circulatory problems (e.g., orthostatic hypotension (drop in blood pressure), poor blood circulation from cardiomyopathy, heart attack, arrhythmia, transient ischemic attack), neurological conditions (e.g., Parkinson's disease, multiple sclerosis), medications (e.g., anti-seizure drugs, antidepressants, sedatives, tranquilizers, blood pressure lowering medications), anxiety disorders, anemia due to low iron levels, hypoglycemia (lowered blood sugar), overheating, dehydration, and traumatic brain injury. The vibratory signal can cause a portion of the vestibular system to move in a manner equivalent to that of a therapeutically effective vibratory signal to treat the above described conditions. Moreover, the vibratory device 200 can be used to assist pilots such as, for example, to train pilots to ignore or reject their vestibular system under specific conditions. The vibratory device 200 can also be used as a stroke diagnostic.

FIG. 4A schematically illustrates an example system 350 for treating vestibular conditions. The system 350 includes a vibratory device 300 and a control unit 360 coupled to the

vibratory device **300** for activating and/or controlling the operation of the vibratory device **300**. The vibratory device **300** can be an electro-mechanical transducer configured to generate vibratory signals when driven and energized by appropriate electrical signals from a signal source. The control unit **360** can include a memory **362**, a processor **364**, and an input/output (I/O) device **366** for receiving and/or sending electrical signals to and/or from other components of system **350**. The vibratory device **300** can be configured to receive and/or send electrical signals to the control unit **360**. Optionally, the system **350** can include a sensor **390** for measuring voltage, current, impedance, movement, acceleration, or other data associated with the vibratory device **300**. The sensor **390** can also be configured to measure information associated with a vestibular system VS of a subject and/or other body metrics (e.g., temperature, skin conductivity, etc.). The sensor **390** can receive and send signals to the control unit **360**, the vibratory device **300**, and/or the vestibular system VS. The system **350** can include a signal generator **370** and/or an amplifier **380**. The signal generator **370** can generate one or more signals that drive the vibratory device **300** to vibrate to produce vibratory signals. The amplifier **380** can be operatively coupled to the signal generator **370** and can amplify the signals from the signal generator **370** prior to the signals being used to drive the vibratory device **300**. The control unit **360** can control the operation of the signal generator **370** and/or the amplifier **380**.

In some embodiments, the signal generator **370**, the amplifier **380**, and/or the sensor **390** can be integrated with and/or form part of the control unit **360**. Alternatively, in other embodiments, the signal generator **370**, the amplifier **380**, and/or the sensor **390** can be separate from but operatively coupled to the control unit **360**. In some embodiments, the vibratory device **300** can include one or more of the control unit **360**, the signal generator **370**, the amplifier **380**, or the sensor **390**.

In some embodiments, the control unit **360** is operable to store specialized instructions for controlling the vibratory device **300**. Such instructions may be stored in memory **362** or in a separate memory. In addition, such instructions can be designed to integrate specialized functions and features into the controller to complete specific functions, methods and processes related to treating vestibular conditions disclosed herein. In some embodiments, the control unit **360** may be programmed with the instructions using a software development kit.

Electrical signals to control the vibratory device **300** may be generated by the control unit **360** based on the stored instructions. These electrical signals may be communicated between the control unit **360** and vibratory device **300** through wired or wireless (e.g., Bluetooth) methods. The electrical signals may include a stored pattern of operation, e.g., the stored instructions accessed by the controller may be used by the controller to generate a series of electrical signals that are sent to the vibratory device **300** to cause the vibratory device **300** to turn “on” or “off” in a pattern that is advantageous to a specific subject based on usage data that has been collected, accumulated, and stored for that user. One pattern may involve a series of vibratory signals where the number of vibratory signals generated and applied over a time period (e.g., per minute) to a subject may be varied, while a second pattern may include a series of vibratory signals where the force level in a number of vibratory signals may be varied. Other types of control signals, such as those that may be used to control the force level and frequency of vibratory signals generated by the vibrating device **300**, may

be sent to the vibrating device **300** from the control unit **360** based on data received from sensors (e.g., sensor **390** or other sensors). For example, an acceleration sensor may be included in a portable electronic device (e.g., mobile phone) to sense changes in a user’s physical acceleration. In an embodiment, the control unit **360** may be operable to receive data from the acceleration sensor indicating a type of acceleration that may lead to motion sickness. Accordingly, after receiving such data, the control unit **360** may be operable to generate associated electrical signals and send such signals to the vibrating device **300**. The vibrating device **300**, in turn, may be operable to receive such electrical signals and generate vibratory signals that can be conducted via bone and applied to the vestibular system to, for example, pre-emptively account for motion sickness. The vibratory signals can cause a portion of the vestibular system to move in a manner equivalent to that of a therapeutically effective vibratory signal. For example, the vibratory signals can cause a portion of the vestibular system (e.g. the hair bundles forming the receptors in the semicircular canals and/or the otolith organs) to move in a random manner simulating a noisy vestibular signal or a noisy vestibular sensation. In some instances, such noisy vestibular sensations can induce a reduction in the effects caused by other vestibular signals or a mismatch in signals perceived by a subject. Alternatively, a stored roadmap that represents a path or course that has previously resulted in a user becoming sick due to motion sickness may be stored in the control unit **360** or in the portable device along with a suitable positioning system such as, for example, Global Positioning System (GPS), Galileo, GLONASS, or Beidou. In some embodiments, as the positioning system indicates that the user is moving along the path or course and arrives at a position that may induce motion sickness, the control unit **360** may be operable to generate associated electrical signals and send such signals to the vibrating device **300**. The vibrating device **300**, in turn, may be operable to receive such electrical signals and generate vibratory signals that can be conducted via bone and applied to the vestibular system to, for example, pre-emptively account for motion sickness before the user reaches the position, for example.

FIG. 4B schematically illustrates another example system **350'** for treating vestibular conditions, according to an embodiment. The system **350'** can be similar to the system **350**, in that it includes a control unit **360** and a vibratory device **300** coupled to and energized and/or controlled by the control unit **360**. Additionally, the system **350'** can have a second vibratory device **300'**, also coupled to the control unit **360**, whose activation can be controlled by the control unit **360**. The control unit **360** can be configured to control the vibratory devices **300** and **300'**, such that vibratory signals generated by the vibratory devices **300** and **300'** can be delivered simultaneously, alternately, and/or independently. While not depicted in FIG. 4B, similar to the system **300** depicted in FIG. 4A, system **350'** can optionally include a signal generator (e.g., signal generator **370**) coupled to the control unit **360**, an amplifier (e.g., amplifier **380**) coupled to the signal generator, and/or a sensor (e.g., sensor **390**). In some embodiments, the two vibratory devices **300**, and **300'** can be coupled to a balance **382** that is configured to distribute signals generated by a signal generator and optionally amplified by an amplifier between the vibratory devices **300** and **300'**. In some embodiments, the vibratory devices **300** and **300'** can be coupled to each other and configured to send and/or receive signals from each other. While two vibratory devices **300** and **300'** are depicted in FIG. 4B, one

of ordinary skill in the art would appreciate that any number of vibratory devices can be used.

FIG. 5 is a schematic illustration of an example vibratory device 400, according to an embodiment. The vibratory device 400 includes a body (or a housing) 410 that can define one or more chambers. The body 410 houses a vibratory element 423, a suspension element 420, a driving circuit 440, and a delivery interface 430. The vibratory element 423 is configured to be suspended by the suspension element 420 and driven by the driving circuit 440 to move (e.g. oscillate or vibrate) to produce the vibratory signal. The vibratory element 423 can be suspended within the body (e.g. in a chamber) such that the vibratory element 423 can vibrate about an equilibrium position. The movement of the vibratory element 423 can be with respect to the suspension element 420 and/or the body 410 of the vibratory device 400 to produce vibratory signals that can be directed via the delivery interface 430 to treat one or more vestibular conditions as disclosed herein. The vibratory device 400 and/or the body 410 of the vibratory device 400 can be positioned on a head of a subject with the delivery interface 430 on or against a target area TA such that the vibratory signals produced by the movement of the vibratory element 423 can be applied to the target area TA, which can then be conducted via a bone structure BS to a vestibular system VS of the subject.

Optionally, in some embodiments, the vibratory device 400 can include an onboard power source 414 to provide power to components of the vibratory device 400, and a sensor 416 to sense one or more signals from a portion of the vibratory device 400, the vestibular system VS, or another portion of the body (e.g., a portion of the body against which the generated vibratory signals are applied such as, for example, the target area TA or skin adjacent to and/or associated with the target area TA). In some embodiments, a remotely situated power source (e.g., a power source contained in control unit 360) can be used to power the vibratory device 400. In some embodiments, a remote sensor (e.g., a sensor 390) can be used to sense signals from a portion of the vibratory device 400, the vestibular system VS, or another portion of the body (e.g., a portion of the body against which the generated vibratory signals are applied).

The sensor 416 can be configured to measure and/or record information associated with the vibratory device 400 and/or the subject (e.g., the vestibular system VS, the target area TA, etc.). For example, the sensor 416 can include one or more suitable transducers to measure and/or record information from the vibratory device 400, including a current, a voltage (e.g., a voltage change associated with the electrical signal across the vibratory element 423), a magnetic field (e.g., a directional magnetic field generated by the electrical signal and applied near the vibratory element 423), or an acceleration of the vibratory element 423 during movement, etc.

In some embodiments, the sensor 416 can be used to increase an efficiency of the vibratory device 400. For example, the sensor 416 can include an ammeter for monitoring the current of an electrical signal coming from the vibratory element 423 and/or another portion of the vibratory device 400. A frequency of the electrical signal being supplied to the vibratory device 400 can be adjusted until a low current is measured by the ammeter, with the rationale that, at a resonant frequency of the vibratory device, the impedance of the vibratory device 400 is higher than at other frequencies and therefore the current lower than at other frequencies (assuming a constant voltage). Accordingly, the

ammeter can be used to tune (e.g., adjust) the frequency of the electrical signal to the resonant frequency, such that the vibratory device 400 operates efficiently. That is, the vibratory device 400, in some embodiments, can include a processor configured to receive the information from the sensor 416 (e.g., information from the ammeter) and adjust the frequency of the electrical signal based on the information. For example, the processor can be configured to adjust the frequency of the electrical signal over time such that the vibratory device continues to operate at a reduce current and at a lowest resonant frequency.

As another example, the sensor 416 may include a voltage sensor or a voltmeter with a constant current amplifier. Voltage changes in the electrical signal supplied to a portion of the vibratory device 400 including the vibratory element 423 can be measured using the voltmeter. A frequency of the electrical signal being supplied to the vibratory device 400 (e.g. from a suitable signal source) can be adjusted until a high voltage is measured by the voltmeter, with the rationale that, at a resonant frequency of the vibratory device, the impedance of the vibratory device 400 is higher than at other frequencies and therefore the voltage higher than at other frequencies. Accordingly, the monitored voltage may be used to tune (e.g., adjust) the frequency of the electrical signal such that a high voltage is measured to achieve high efficiency.

As another example, where the vibratory element 423 is driven by a modulated magnetic field, the sensor 416 can include a Hall effect sensor that monitors magnetic field fluctuations. The magnetic field fluctuations can be measured, while a frequency of the electrical signal being used to generate the magnetic field is varied, to tune the frequency of the electrical signal to be at a resonant frequency of the vibratory device 400. As another example, the sensor 416 can include a movement sensor (e.g., an accelerometer) that can measure an acceleration and/or a velocity of the vibratory element 423 to determine when a resonant frequency is achieved.

The sensor 416 can also be equipped to receive and/or measure information from the subject such as movement associated with vibratory signals that are transferred to the bone structure of the subject, a temperature of the subject, an orientation or body position of the subject, etc.

The vibratory device 400 can also include a support element 418 to support or position the vibratory device 400 on or against the target area TA of the subject to deliver the vibratory signals, as disclosed herein. The support element 418 can be a device or fastening feature that can maintain contact and positioning of the vibratory device 400 with respect to the subject. For example, the support element 418 can be a head band, eye glasses, or a pillow, and so forth as disclosed in detail further below. In some embodiments, the support element 418 can be an adhesive component, such as, for example, an adhesive pad, a tacky polymer, etc. that can maintain contact and positioning of the vibratory device 400.

The power source 414, the sensor 416, and/or the support element 418 can be housed within and/or attached to the body 410 of the device 400.

The target area TA of the subject to which vibratory signals are applied may be, for example, a surface of the head. Optionally, in some embodiments, the vibratory device 423 may be implanted in the subject's head, and the target area TA can be a region that is proximate to and/or part of bone structure BS. The vibratory device can be configured to be engageable with the target area TA to effectively deliver therapeutic vibratory signals. In an example instance,

the target area TA can be an area behind an external ear of a subject that overlays a mastoid process (or mastoid bone or mastoid process of the temporal bone) of a skull of the subject. In such instances, the mastoid bone may form part of the bone structure BS used to deliver vibratory signals to the vestibular system VS, via the bony structures of the inner ear housing the vestibular system VS. In some instances the zygomatic bone or the zygomatic process of the temporal bone can be a portion of the bone structure BS used to deliver vibratory signals to the vestibular system VS. In other instances, the target area TA can be a portion of a back of the head or the forehead, with the underlying regions of the skull acting as the bone structure BS that conducts the vibratory signals received from the vibratory device 400. Based on the target area TA selected and its distance from the vestibular system VS, varying force levels can be used to operate the vibratory device 400. For example, when the device is placed on a target area TA such as the forehead area of a subject or behind the head of a subject, regions that are further away from the vestibular system VS than the mastoid process, a higher force level may be used as compared to when the device is placed overlaying the mastoid process of the subject. As an example, when placed on the forehead or being the head of a subject, the vibratory device 400 can be configured to apply vibratory signals with a force level up to 14 dB greater than the force level of vibratory signals that may be therapeutically effective when delivered elsewhere (e.g., region overlying the mastoid bone). When the target area TA is an area overlaying the mastoid bone and the vibratory device is placed overlaying that area, a therapeutically effective force level can be between 90-100 dB re 1 dyne, and desirably, between 93-98 dB re 1 dyne, for treating a vestibular condition.

The body 410 of the vibratory device 400 can be configured to house various components of the vibratory device 400. In some embodiments, the body 410 can house some of the components while providing an interface for the coupling of one or more components that are not housed within the body 410, such as the power source 414, the sensor 416, and/or the support element 418. In some embodiments, the body 410 of the vibratory device 400 can define one or more chambers or receptacles for housing one or more components of the vibratory device such as the vibratory element 423, the suspension element 420, the driving circuit 440, and/or the delivery interface 430. The body 410 can also be shaped and/or configured for desired positioning of the delivery interface 430 against the target area TA of the subject's body (e.g., the body 410 can have a curved surface, or a surface that is malleable or flexible). In some embodiments, the body 410 and/or one or more of its chambers may be filled with air or in some instances a liquid such as a lubricant to aid in the generation and delivery of the vibratory signals. In some embodiments, the body 410 and/or one or more of its chambers may also include materials of having properties such as, for example, audible noise dampening agents such as sponges or sound absorbing materials, heat dissipation materials, etc.

The vibratory element 423 of the device 400 can be configured to oscillate or vibrate to generate the vibratory signal. In some embodiments, the vibratory element 423 can be housed within a chamber of the body 410. The vibratory element 423 can be suspended at an equilibrium position by the suspension element 420, and an electrical signal can be used to cause the vibratory element 423 to vibrate or oscillate about the equilibrium position to generate a vibratory signal. Properties of the vibratory element 423 and/or suspension element 420, such as the material, composition,

structure etc., can be chosen to meet specific requirements of the generated vibratory signals (e.g., a low frequency signal).

For example, the vibratory element 423 can be a spring or an elastic material with a measure of stiffness (e.g., a spring constant) that enables generation of vibratory signals of a low frequency (e.g., a frequency of less than 200 Hz) with high efficiency. In an embodiment, the vibratory element 423 can be a mass that is suspended by a suspension element 420 that is a spring. The natural resonance of such a system can be determined based on Hooke's Law, as represented by the equation

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}},$$

where f is the resonant frequency, k is the spring constant, and m is the mass. The amplitude of movement of the mass is greater at the resonant frequency than at other frequencies, for a given power, since the mass and spring system at the resonant frequency can be associated with a purer tone (e.g., a sinusoidal waveform). Accordingly, operating the vibratory device 400 at its resonant frequency produces a stronger vibratory signal, and properties of the vibratory element 423 and/or suspension element 420 can be selected to achieve a particular resonant frequency.

Other factors that can affect and/or determine the generated vibratory signal can be, for example, the mechanism of the driving force (e.g., mechanical, magnetic), the ease of movement of the vibratory element (e.g., how frictionless is the movement), the location of the target area TA (e.g., the mastoid bone, the zygomatic bone, the skull near the forehead of a subject, etc.), reduced secondary or tertiary paths of energy dissipation (e.g., off-axis movement, heat, friction, etc.), direction of movement with respect to external forces (e.g., pressure during use, gravitational forces, etc.), requirements for ease of use by the subject under varied conditions (e.g., mobility of the subject, limitations on level of distractions, etc.), and so forth.

The vibratory element 423 can be configured such that it can be driven to generate vibratory movements along or about an axis of the vibratory device 400 (e.g., a longitudinal axis of the body 410), where the movements produce vibratory signals with suitable properties (e.g. frequency, amplitude, force level, etc.) for treating vestibular conditions. The vibratory device 400, in some embodiments, can be an electromechanical transducer including, for example, a vibratory element 423 implemented as a magnet that can be driven to move along an axis using a suitable driving force such as a magnetic field. Further details regarding such embodiments are described below with reference to FIGS. 6-9C.

Another method to produce a low frequency vibratory signal is to modulate an ultrasonic signal. In some embodiments, the vibratory device 400 can be a piezoelectric transducer driven by an electrical signal to generate vibrations in the ultrasonic frequency range. The vibrations of the piezoelectric transducer at this higher frequency can produce acoustic radiation pressure. The driving electrical signal can be clocked on and off at a lower frequency, less than 200 Hz (e.g., 60 Hz), such that the pressure from the piezoelectric transducer applied on and off at the lower frequency generates a corresponding vibratory signal at the lower frequency. The use of a piezoelectric transducer can reduce a size and weight of the vibratory device 400, as piezoelectric

transducers are typically smaller and lighter than other types of electro-mechanical transducers.

Depending on where the vibratory device **400** is placed, the dimensional restrictions of the vibratory device **400**, and/or the configuration or shape of the vibratory device **400**, specific components of the vibratory device **400** can be selected to provide a therapeutically effective level of vibratory signal to treat a vestibular condition. While one vibratory element **423** is illustrated in FIG. **5**, one of ordinary skill in the art would appreciate that vibratory device **400** can include one or more additional vibratory elements, which can work together and/or independently to generate vibratory signals to treat a vestibular condition.

Similar to other vibratory devices or systems, the vibratory device **400** can be associated with a set of resonant frequencies. In some embodiments, the vibratory element **423** may be configured to move in response to a driving force such that the amount of power of the generated vibratory signals at a lowest resonant frequency associated with the vibratory device **400** is greater than the amount of power of the vibratory signals at the remaining resonant frequencies (e.g., higher resonant frequencies) associated with the vibratory device **400**. For example, a vibratory device may be configured to have a lowest resonant frequency between 50 and 70 Hz, and the vibratory signals generated at the lowest resonant frequency in this range can be of greater amount of power than vibratory signals that may be generated at other resonant frequencies. In some embodiments, the vibratory element **423**, the suspension element **420**, and/or other elements of the vibratory device **400** can be selected such that the vibratory device **400** vibrates at a lowest fundamental frequency of less than 200 Hz.

In some embodiments, the vibratory element **423** can vibrate at a first resonant frequency along a first axis (e.g., an axis in a z-direction) and also vibrate at a second resonant frequency along secondary axes (e.g., an axis in a x-y plane). To reduce the vibrations along the secondary axes, the vibratory element **423**, the suspension element **420**, and/or other elements of the vibratory device **400** can be selected such that the first resonant frequency is not a harmonic of the second resonant frequency, and vice versa (e.g., the first resonant frequency is a few hertz offset from the second resonant frequency and/or a harmonic of the second resonant frequency), such that vibrations along the secondary axes can be reduced when the vibratory device **400** is stimulated at the first resonant frequency. Vibrations along the secondary axes can, for example, lead to internal collision between components of the vibratory device **400** and/or audible sound.

The vibratory device **400** can be positioned in different areas on a head of a subject. FIG. **16** depicts a human skull and indicates some example regions of the skull where the vibratory device **400** may be positioned, to apply therapeutic vibratory signals to treat vestibular conditions disclosed herein. For example, as indicated in FIG. **16**, the vibratory device **400** can, in some instances, be placed over a mastoid bone **1502** of the subject's skull. While a left mastoid bone **1502** is identified in FIG. **16**, one of ordinary skill in the art would appreciate that the vibratory device **400** can be placed over a left or right mastoid bone of a subject. In other instances, the vibratory device **400** can be placed over a portion of the back of the head (e.g. over a left, right, or central portion of an occipital bone **1501**) or over a portion of the forehead (e.g. a left, right or central portion of a frontal bone **1504**) to deliver vibratory signals to treat vestibular and other conditions disclosed herein. Depending

upon the region that the vibratory device **400** is placed (e.g., its proximity to the vestibular system, whether vibrations from the device need to traverse a suture line **1503**), a force level of the vibratory signals may be adjusted such that a therapeutically effective level of vibration for treating a condition is delivered to the vestibular system.

When the vibratory device **400** is positioned overlaying a mastoid bone (e.g. mastoid bone **1502** shown in FIG. **16**), the vibratory device **400** can apply a vibratory signal that is therapeutically effective at treating a condition of the vestibular system (i.e., a therapeutically effective vibratory signal) having a resonant frequency of less than 200 Hz and a force level between 90 and 100 dB re 1 dyne. If the vibratory device **400** is positioned overlaying a different area of the subject's head that is further from the subject's vestibular system than the mastoid bone, (e.g., a zygomatic bone **1505**, or a frontal bone **1504** or an occipital bone **1501**, shown in FIG. **16**), then the vibratory device **400** can generate a vibratory signal that has a greater force level such that the vibratory signal can affect a portion of the vestibular system in a manner equivalent to a therapeutically effective vibratory signal that is applied to an area overlaying the mastoid bone (e.g., **1502** shown in FIG. **16**). For example, when the vibratory device **400** is positioned over a frontal bone of a subject (e.g., frontal bone **1504** in FIG. **16**), the vibratory device **400** can generate a vibratory signal having a force level that is greater than the force level of a therapeutically effective vibratory signal that is applied to an area overlaying the mastoid bone (e.g., up to 14 dB re 1 dyne greater).

The suspension element **420** of the vibratory device **400** can include one or more components that are housed in the body **410**, and that interact with the vibratory element **423**. In some embodiments, the suspension element **420** and/or the vibratory element **423** can be configured with adaptations to accommodate each other. For example, the suspension element **420** can include components that can extend through openings defined in the vibratory element **423**.

In some embodiments, the suspension element **420** can be housed within a chamber of the body **410**, and in some instances, can be disposed in a fluid such as a lubricant. The suspension element **420** can be configured to apply a force on the vibratory element **423** to suspend, hold or support the vibratory element **423** in a position of equilibrium until driven to move by the application of a driving signal. For example, the suspension element **420** can be a spring coupled to a vibratory element **423** (e.g. a magnet). Alternatively or additionally, the suspension element **420** can include a pair of magnets in an arrangement with the vibratory element **423** (e.g., another magnet) to each apply a force on the vibratory element **423** in an opposing direction (e.g., opposing or repulsive magnetic forces) to collectively hold the vibratory element **423** in an equilibrium position by virtue of forces acting between them (e.g. the opposing or repulsive magnetic forces). In such embodiments, a driving force (e.g. an applied magnetic field of a specific magnitude and acting along specific directions) can induce the vibratory element **423** (e.g. the magnet in equilibrium position) to move between the pair of magnets. In other embodiments, the suspension element **420** can be an elastic material or fluid. While one suspension element **420** is depicted in FIG. **5**, one of ordinary skill in the art would understand that a plurality of suspension elements **420** can be used to support and/or suspend the vibratory element **423**. The plurality of suspension elements **420** can include one or more different types of suspension elements (e.g., a magnet, a spring, an elastic material, etc.).

The driving circuit **440** of the vibratory device **400** can include one or more suitable components that can generate an electrical signal. The electrical signal can cause a force to be generated to induce movement of the vibratory element **423** along an axis to produce therapeutic vibratory signals. The driving circuit **440**, in some embodiments, can receive the electrical signal from a control unit (such as the control unit **360** in FIGS. **4A** and **4B**). In some other embodiments, the driving circuit **440** can itself include an onboard unit that can generate the electrical signal.

The electrical signal generated or received by the driving circuit **440** and used to induce movement of the vibratory element **423** can be of suitable properties to produce a vibratory signal having specific frequency and force levels. For example, the electrical signal can be selected such that it causes the vibratory element **423** to produce vibratory signals that have a particular range of frequencies (e.g., less than 200 Hz) to treat one or more specific vestibular conditions. In some embodiments, a control unit (e.g., control unit **360**) can be capable of changing a frequency of the electrical signal until the electrical signal causes the vibratory device **400** to vibrate at a resonant frequency, such as described above with sensor **416**.

In some embodiments, the driving circuit **440** can include an onboard signal generator to generate the electrical signal, an amplifier to amplify the signal, and one or more elements for converting the electrical signal into the appropriate modality that causes the vibratory element **423** to move. For example, the driving circuit **440** can include one or more coils that can generate a magnetic field that moves the vibratory element **423**.

The delivery interface **430** of the vibratory device **400** can be configured to transfer the vibratory signals generated by the vibratory element **423** to the target area TA of the subject, such that the vibratory signals can be conducted via the bone structure BS beneath to the vestibular system VS. The delivery interface **430** can be configured for and/or adaptable to the structure and/or shape of the target area TA of the user such that the delivery interface can engage with and/or maintain contact during the period of use for transfer of the therapeutic vibratory signals. In some embodiments, the delivery interface **430** can be configured with considerations of comfort and ease of use for the user, for example, during use of the vibratory device **400** to mitigate a vestibular conditions. The delivery interface **430** may further be configured to reduce secondary effects that may be undesirable such as the generation and accumulation of heat, generation of audible noise, lack of air circulation, application of pressure against the target area TA, etc. For example, the delivery interface **430** can include a layer of memory foam material that may aid in adapting to the contours of the target area (e.g., a region behind the ear overlying the mastoid process). The memory foam material may also aid in heat dissipation, dampening of audible noise, encourage air circulation, minimize discomfort from pressure applied by a support element such as a head band, etc.

FIG. **6** is an illustration of an example vibratory device **500** according to one embodiment. The vibratory device **500** includes a body (or housing) **510** that includes a tubing **526** and end caps **525a**, **525b**. In some embodiments, the body **510** of the vibratory device **500** can define a chamber. The body **510** houses a vibratory element implemented as a magnet **523** and suspension elements implemented as magnets **520a**, **520b**. As shown in the cut-away view in FIG. **6**, the suspension elements include magnets **520a**, **520b**, and the vibratory element **523** includes a magnet **523**. The magnets **520a**, **520b** act as suspension elements by exerting

opposing forces on the magnet **523** to suspend the magnet **523** at an equilibrium position, as shown in FIG. **6**. For example the magnet **520a** can be configured to apply a force on the first magnet **523** in a first direction and the magnet **520b** can be configured to apply a force (e.g. a force equivalent in magnitude to that exerted by the second magnet **520a** on magnet **523**) on the first magnet **523** in a second direction (e.g. a second directions 180° removed from the first direction). As such the first magnet **523** can be disposed between the second magnet **520a** and the third magnet **520b** in the body **510** (e.g. a chamber) such that the second magnet **520a** and the third magnet **520b** collectively suspend the first magnet **523** at a position (e.g. an equilibrium position) within the body **510**.

The magnet **523** acts as the vibratory element configured to move (e.g., oscillate or vibrate) to produce the vibratory signal. The vibratory element **523** can be collectively suspended by the suspension elements **520a**, **525b** within the body **510** (e.g., in a chamber) such that the vibratory element **523** can vibrate about an equilibrium position.

In some embodiments, the vibratory device **500** can include an elongate member having a longitudinal axis. The elongate member can be configured to extend through an opening in the vibratory element **523** such that the vibratory element **523** can be configured to vibrate along the longitudinal axis of the elongate member. The elongate member can further be configured to reduce oscillations or vibrations of the vibratory element **523** along any axis other than the longitudinal axis. As shown in FIG. **6**, the vibratory device **500** further includes an elongate member in the form of a pin **521** that can be secured to the end caps **525a**, **525b**. The pin **521** passes through openings **522a**, **522b** defined in the end caps **525a**, **525b** of the vibratory device **500**, openings defined in the magnets **520a**, **520b**, and an opening defined in the magnet **523**. The pin **521** provides an axis for movement of the magnet **523** (e.g., along a longitudinal axis of the pin **521**). The vibratory device **500** further includes a driving circuit that includes a coil **524** configured to generate a magnetic field capable of driving the vibratory device using an electrical signal. The vibratory device **500** includes a bushing **522c** configured to fit in the opening defined in the magnet **523**, and configured to interface between the pin **521** and the magnet **523** allowing smooth movement of the magnet **523** over the pin **521**.

In operation, the vibratory device **500** is driven using an electrical signal that comprises a sine wave or another type of signal waveform at a low frequency (e.g., less than 200 Hz). The coil **524** is operable to generate a magnetic field with an induced electrical current. The magnetic field in turn applies a magnetic force on magnet **523**. The magnetic force, when applied to the magnet **523**, causes the magnet **523** to move along the axis indicated by the arrow "A" in FIG. **6**. The magnet **523** is configured to move in either of the directions indicated depending on the direction of the magnetic field vector.

Magnets **520a** and **520b**, forming the suspension element, each create a constant magnetic field, each of which is applied to magnet **523** (i.e., a north side of magnet **520a** will face a north side of magnet **523** and a south side of magnet **520b** will face a south side of magnet **523**). Accordingly, the magnets **520a**, **520b** apply opposing forces on the magnet **523**. The opposing forces created by magnets **520a**, **520b** are operable to suspend the magnet **523** at the equilibrium position such that the magnet **523** oscillates about the equilibrium position and generates the one or more vibratory signal signals. The electrical signal will cause the magnet

**523** to oscillate or move along the axis A, which can be the same as or may substantially correspond with a longitudinal axis of the pin **521**.

In some embodiments, to ensure that the magnets **520a**, **520b** and **523** do not oscillate or move in a direction other than along the axis A, which may affect the efficiency of the system and increase undesirable friction that causes secondary vibratory signals (e.g., a humming sound), the vibratory device **500** can be configured such that the motion of magnet **523** is restricted by the pin **521**. In some embodiments, each of the magnets **520a**, **520b**, can be secured to the end caps **525a**, **525b** of the vibratory device **500** with a glue, epoxy, or another form of adhesive. The magnet **523** can be fitted around the pin **526** with the bushing **522c** interface allowing the magnet **523** to smoothly move over the pin **521** while restricting any motion that is not along the axis A. Glue, epoxy, or any other form of adhesive may also be used to secure the pin **521** to the end caps **525a**, **525b** through openings or holes **522a**, **522b**.

In some embodiments, the tubing **526** may contain and/or include on its inner surface a lubricant (e.g., ferrofluid) or a low friction material (e.g., polytetrafluoroethylene), configured to reduce the potential friction between the magnet **523** and the inner surface of the tubing **526**. Reduced friction can be configured to ensure a quieter operation of the vibratory device **500** (e.g., with less noise generated by the potential friction from contact). Such lubricants may also be used to reduce the friction between the bushing **522c** and the pin **521**.

In some embodiments, the outer surface of the tubing **526** and/or endcaps **525a**, **525b** can be covered with a sound absorbing material. Further, in some embodiments, one or more of the endcaps **525a**, **525b** can be covered with a friction reducing material (e.g., a smooth material) or an impact absorbing or padded material, such as, for example, cork, so that when that endcap comes into contact with a person's skin or body the contact is less abrasive than if the endcaps **525a**, **525b** were not covered by such material. Further, in some embodiments, one or more of the endcaps **525a**, **525b** may be attached to a structure that increases a surface area of that endcap, so that when that endcap comes into contact with a person's skin or body, the contact is spread over a larger area reducing the pressure exerted by that endcap on the skin or body.

It should be understood that the magnets **520a**, **520b** are one example of elastic objects that can be used to form the suspension element in the vibratory device **500**. In other embodiments, the magnets **520a**, **520b** may be replaced by other elastic objects (e.g., springs, an elastic polymer).

FIG. 7A illustrates an embodiment of the vibratory device **600** that includes springs as suspension elements. The vibratory device **600** can be similar to the vibratory device **500** depicted in FIG. 6 described above. For example, the vibratory device **600** can include a housing **610** including a tubing **626** (e.g. a Nylon tubing) and end caps **625a**, **625b**. The vibratory device **600** can further include a magnet **623** forming the vibratory element, and a driving circuit including a coil **624** to drive movement of the magnet **623** to produce the vibratory signals used to treat vestibular conditions disclosed herein.

As shown in the cross-sectional schematic in FIG. 7A, the vibratory device **600** can include suspension elements implemented as springs **620a**, **620b**, instead of the magnets **520a**, **520b** in the vibratory device **500** shown in FIG. 6. The magnet **623** can be collectively suspended by the springs **620a**, **620b**, within the housing **610** (e.g. in a chamber) such

that the magnet **623** can vibrate about an equilibrium position when energized by an electrical signal.

As described above with reference to the vibratory device **500**, in some embodiments, the vibratory device **600** can include an elongate member having a longitudinal axis. The elongate member can be configured to extend through an opening in the vibratory element magnet **623** such that the magnet **623** can be configured to vibrate along the longitudinal axis of the elongate member. The elongate member can further be configured to reduce oscillations or vibrations of the magnet **623** along any axis other than the longitudinal axis.

The springs **620a**, **620b**, may be supported by the elongate member, cavities in end caps **625a**, **625b** and/or other suitable structure(s) extending from the end caps (not shown in FIG. 7A) such as, for example, a rigid and/or flexible structure (e.g., a pin, foam, rubber, or any another material). The springs **620a**, **620b**, can be configured to expand and compress along an axis (e.g. a longitudinal axis) and the magnet **623** mounted to the springs **620a**, **620b**, configured to oscillate or vibrate along the same axis to produce therapeutic vibratory signals. The springs, used as the elastic objects forming the suspension element, can be secured to other parts of the vibratory device **600** (e.g., to the magnet **623**, tubing **626**, and/or end caps **625a**, **625b**) using a glue, epoxy, or any form of adhesive. The springs **620a**, **620b**, can be configured to reduce oscillations of the magnet along any axis other than the axis (e.g. longitudinal axis) of the springs.

The springs **620a**, **620b** can be of any suitable material (e.g., stainless steel), and be chosen to have certain stiffness, for spring constant  $k$ , such that they allow movement of the magnet **623** along an axis indicated by the labeled arrow "B," when driven by an electrical signal. The springs **620a**, **620b** can be configured such that they are attached to the magnet **623** and a portion of the housing **610**. For example, each spring (**620a** and **620b**) can have a first end that may be attached to a portion of the housing **610** and a second end attached to the magnet **623**. As such, the springs can be configured to apply a force on the magnet to suspend the magnet at the position within the chamber. For example, the springs **620a** and **620b** can each exert an equivalent force in an opposite direction such that with movement of the magnet **623**, as one spring (e.g. **620a**) expands the other spring (e.g. **620b**) may contract and vice versa, such that the magnet **623** may oscillate or vibrate along an axis (e.g. the longitudinal axis of the springs) the movement of the magnet **623** may be configured to be about the position of suspension (e.g. an equilibrium position). The vibratory device **600** can include one or more glue pockets **632**, **634** as points of coupling between the springs **620a**, **620b** and the magnet **623**, respectively.

In some embodiments, the springs **620a**, **620b** are operable to prevent contact between the magnet **623** and the inner surface of the tubing **626**. As described above with reference to the vibratory device **500**, the tubing **626** of the vibratory device **600** can contain and/or include on the inner surface a lubricant (e.g., ferrofluid) or a low friction material (e.g., polytetrafluoroethylene), to reduce potential friction from any contact between the magnet **623** and the inner surface of the tubing **626** during movement of the magnet **623**. In some embodiments, a rod or pin (not shown in FIG. 7A) and a bushing (not shown in FIG. 7A) may be included to further limit a movement of the magnet **623** in directions other than along axis B.

FIG. 7B illustrates a cross sectional view of the vibratory device **600** from FIG. 7A, attached to a delivery interface **630** for delivering the therapeutic vibratory signals. As



described before the magnet **623** acts as the vibratory element suspended by the springs **620a**, **620b**. The delivery interface **630** can be a memory foam pad configured to transfer vibratory signals from the vibratory device **600** to the body of the subject. While magnets and springs have been provided as examples of suspension elements, one of ordinary skill in the art would understand that other types of elastic objects may be used in lieu of and/or in addition to magnets and/or springs.

The vibratory devices disclosed herein (e.g., vibratory devices **400**, **500**, **600**, **700**) can have high Q factors (e.g., be capable or oscillating with greater amplitudes at a narrow range of frequencies). In some embodiments, a vibratory device can be operable at a lowest, fundamental frequency, such as a frequency between 50-70 Hz, with a low amount of power being directed to upper and more audible resonant frequencies.

FIG. **8** illustrates a cross-sectional view of a vibratory device **700** according to an embodiment. The vibratory device **700** can be similar to the vibratory devices **500**, **600**. For example, the vibratory device **700** can include a housing **710**, a vibratory element implemented as a magnet **723**, a suspension element implemented as a spring **720**, and a driving circuit including a coil **724** to drive movement of the magnet **723** to produce the vibratory signals used to treat vestibular conditions disclosed here. The magnet **723** can be suspended by the spring **720**, within the housing **710** (e.g. in a chamber) such that the magnet **723** can vibrate about an equilibrium position when energized by an electrical signal delivered by the driving circuit.

In some embodiments, to reduce the spring constant of the spring **720**, thereby affecting the resonant frequency of the vibratory device **700**, a length of the spring **720** can be increased, which can allow for the generation of lower frequencies. In order to change the length of the spring without altering the size of the vibratory device **700**, the spring **720** can be configured to pass through an opening **723a** defined by the magnet **723**. As shown in FIG. **8**, the spring **720** can be attached to a mounting plate **728** and adhered to the far side of the magnet **723** rather than be attached to the near side of the magnet **723**. In this way, a length of the vibratory device **700** can remain the same while a length of the spring **720** can increase by a length equal to or substantially equal to the thickness of the magnet **723**. In some embodiments, as an alternative to having a mounting plate **728**, the magnet **723** can have an opening that extends through a portion of its length (e.g., approximately 95% of its length), and the spring **720** can extend through the opening and attach to the far end of the magnet **723**, similar to how the spring **720** would attach to a mounting plate **728**.

Similar to the vibratory device **600** as depicted in FIG. **7B**, the vibratory device **700** illustrated in FIG. **8** can also be attached to a delivery interface (e.g., a delivery interface **730**) to deliver vibratory signals to a subject's vestibular system. The delivery interface **730** can include a padded material, such as a memory foam pad, to conform to a surface of a target area and act as an interface between the vibratory device **700** and the target area, to effectively deliver the vibratory signals.

As shown in FIG. **8**, some embodiments of the vibratory device can include an integrated circuit **706** that includes circuitry for generating a signal for activating the vibratory device **700**. The integrated circuit **706** can include one or more leads or connection points **708** (e.g. wire leads) to connect to other components (e.g. a control unit **360** such as a microcontroller). The integrated circuit **706** can also include and/or be coupled to a sensor **790**.

The vibratory device **700** can have a high Q factor. In operation, a frequency of a signal being used to activate the vibratory device **700** may be selected such that the vibratory device **700** operates at a resonant frequency to increase an amplitude of the oscillations for a given power input. In an embodiment, the sensor **790** can include a Hall effect sensor that is configured to monitor magnetic field fluctuations. When the frequency of the electrical signal supplied to the vibratory device **700** from a signal source that can vary force level and/or frequency (e.g., signal generator **370** and/or amplifier **380**) matches a resonant frequency of the vibratory device **700**, the magnet **723** can move further (e.g., oscillate or vibrate with greater amplitude) than at other frequencies. Accordingly, magnetic field fluctuations caused by the oscillations of the magnet **723** can increase when the frequency of the electrical signal matches a resonant frequency of the vibrating device **700**. This relative fluctuation can be monitored using a Hall effect sensor.

In more detail, a microcontroller or microprocessor (e.g., a control unit **360**) may be operable to receive signals from the Hall effect sensor and adjust a frequency of the electrical signal used to power the vibratory device **700** based on the sensor readings. For example, the microcontroller may be operable to scan through a set range of frequencies (e.g., 50-65 Hz) and select a frequency of the electrical signal that generates the highest level of magnetic field fluctuations. This process may be referred to as "tuning." Thereafter, the combination of the sensor **790** and microcontroller may continue to tune the frequency of the electrical signal supplied to the vibratory device **700** to maintain that efficiency each time the device is turned on. In addition, after a frequency of the electrical signal has been selected, the frequency may be modified around the selected frequency to determine whether the frequency of the electrical signal associated with peak efficiency changes over time due to temperature, wear, or other variables that may cause the properties of components of the vibratory device **700** (e.g., the spring **720**) to change with time.

In some embodiments, the sensor **790** can include an ammeter, a voltmeter, an accelerometer, or some other type of sensor, similar to the sensor **390**, for measuring information (e.g., current, voltage, acceleration, etc.) to be able to select the resonant frequency that provides greatest efficiency.

Integrated circuit **706** can function as an endcap, which further reduces the size of vibratory device **700**. The delivery interface **730** may be, for example, a foam pad operable to function as structure that conforms to the surface of a user's skin and is capable of transferring vibratory signals from the vibratory device **700** to the body, such that it can be conducted via bone to the vestibular system. The delivery interface **730** may be configured such that a good coupling allows an efficient transfer of vibratory signals to the head.

In some embodiments, to avoid audible tones (i.e., noise, humming), the vibratory device **700** may be configured to reduce friction and/or contact between internal structures. For example, the magnet **723**, coil **724**, housing **710**, etc. may be positioned with sufficient tolerances between one another to allow natural rocking and swaying of components while reducing contact between the various components.

Similar to the magnet **623** of the vibratory device **600**, the magnet **723** may also wobble in directions not along the axis C, which may cause the magnet **723** to contact an inner surface of the vibratory device **700**. This contact can make an audible sound and/or reduce an efficiency of the vibratory device **700**. In some such embodiments, noise may be minimized by choosing a spring **720** and magnet **723** whose

properties cause the axial resonant frequency to not be the same as the wobbling resonant frequency or any of its harmonics. Then, in operating the vibratory device **700** at a frequency that corresponds to the axial resonant frequency and not the wobbling resonant frequency can reduce wobbling and unintentional contact between the magnet **723** and other components of the vibratory device **700**.

To adjust the output force level of the mechanical vibratory signals output by the vibratory device **700**, the voltage of the electrical signal input into the vibratory device **700** may be increased. Alternatively or additionally, to adjust the output force level of vibratory signals, the frequency of the electrical signal may be adjusted to the resonant frequency.

FIG. **9A** illustrates a perspective view of a spring **820** that can act as a suspension element in a vibratory device (e.g., the spring **720** in the device **700** described above). The orientation of the spring may reduce the amount of wobbling, rocking, or undesirable movement of the magnet (e.g., the magnet **723**) in secondary directions. As shown in FIGS. **9B** and **9C**, which present views of the two ends of the spring **820**, the spring **820** may be orientated such that a first end **820a** of the spring **820** begins at a  $0^\circ$  position and a second end **820b** of the spring **820** ends at a  $180^\circ$  position. In other embodiments, the spring **820** can begin and end at other degree intervals, e.g.,  $90^\circ$ ,  $270^\circ$ , etc. depending on an effect of gravity on the vibratory device (e.g., a orientation of the spring **820** relative to a direction of gravity). In some embodiments, the orientation of spring **820** can be selected based on the placement of a sensor, such as, for example, an accelerometer or a Hall effect sensor.

FIGS. **10-15** are illustrations of different embodiments of vibratory devices that can be included and/or integrated into various support elements. While one or two vibratory devices may be depicted in these figures, one of ordinary skill in the art should appreciate that any number of vibratory devices can be included in the various embodiments. In the case of multiple vibratory devices, a force level of the vibratory signals from each device can be reduced since a combined effect of the vibratory signals can be at a therapeutically effective level for treating a vestibular condition.

FIG. **10** illustrates a vibratory device **900** with a body **910** integrated into a headband **918** worn on the head HD of a subject. The vibratory device **900** includes a control unit **906**, similar to control unit **360**, described above. The headband **918** can be made of an elastic, Velcro, metal or plastic, or another material that permits the headband **918** to hold the vibratory device **900** on the head HD of the subject to effectively deliver vibratory signals that can be conducted via bone to the vestibular system. The vibratory device **900** can include an onboard power source (e.g., a battery) to power the control unit **906** and/or other components of the vibratory device **900**, or it may be attached via a wire to a power source (e.g., a battery pack) separate from the headband **918**. The control unit **906** may include the necessary electrical driving circuitry to generate the vibratory signals to treat vestibular or other conditions disclosed herein. Alternatively, such circuitry and power source may be operatively connected to the vibratory device **900**. In some embodiments, the head band **918** may incorporate additional devices such as a headlamp or other suitable head gear to accommodate various needs of a subject.

FIG. **11** illustrates the use of vibratory devices **1000a**, **1000b** integrated into a support element in the form of headphones **1002**, according to an embodiment. The headphones **1002** can include audio speakers **1003a**, **1003b** and an elongated portion **1018** (e.g., band) that connects the audio speakers **1003a**, **1003b**. In some embodiments, the

headphones **1002** may be a passive noise reduction device such as earmuffs, and not include components like audio speakers. Vibratory devices **1000a**, **1000b** can be similar to any other vibratory device (e.g., vibratory devices **300**, **400**, **500**, **600**, **700**, **800**) described herein. The headphones **1002** may include noise cancellation circuitry that can be used to reduce a level of audible sound caused by vibrations produced by the vibratory devices **1000a**, **1000b** but not cancel other vibration that is conducted to the vestibular system (e.g., via bone as a result of vibratory signals produced by the vibratory devices **1000a**, **1000b**). For example, the system **1002** may include noise cancellation circuitry that generates a signal (or signals) that are out of phase with the audible signals produced by the vibratory devices **1000a**, **1000b** (e.g., at a  $180^\circ$  phase difference). Such an out of phase signal acts to reduce the signal level of such audible signals detected by a subject's vestibular system so that a subject may not hear the audible sounds.

When used in conjunction with headphones **1002**, the vibratory devices **1000a**, **1000b** may be placed adjacent to the audio speakers **1003a**, **1003b**, such that when the audio speakers **1003a**, **1003b** are positioned over the ears, the vibratory devices **1000a**, **1000b** are positioned overlaying the mastoid bones. Alternatively or additionally, in some embodiments, one or more of the vibratory devices **1000a**, **1000b** may be incorporated into ear cups of headphones **1002** that may be co-located with the speakers **1003a**, **1003b** so that an ornamental shape or profile of the headphones **1002** is not affected.

Alternatively or additionally, in some embodiments, one or more of the vibratory devices **1000a**, **1000b** (or additional vibratory devices not depicted) may be placed along the headband **1018**, or extend from a portion of the headphones **1002**. Alternatively or additionally, in some other embodiments, one or more of the vibratory devices **1000a**, **1000b** (or additional vibratory devices not depicted) may be incorporated into an attachment which attaches and detaches to the headphones **1002** so that the user may choose to have the headphones without the vibratory devices **1000a**, **1000b** or have the headphones with the vibratory devices **1000a**, **1000b**.

FIG. **12** illustrates yet another embodiment of vibratory devices **1100a**, **1100b** that may be integrated into, or connected to, a pillow **1110** (e.g., a travel pillow, a cushion, etc.). The location of the vibratory devices **1100a**, **1100b** on the pillow **1110** may be configured such that when a subject rests his or her head on the pillow **1110**, the vibratory devices **1100a**, **1100b** overlay, for example, the mastoid bones of the subject. In other embodiments, the vibratory devices **1100a**, **1100b** can be positioned such that they would overlay other areas of the subject's head.

FIG. **13** illustrates yet another embodiment of a vibratory device **1200** that may be integrated into or connected to a seat **1210** (e.g., a car seat, office chair, etc.). The seat **1210** and the vibratory device **1200** can be configured so that, for example, when a subject's head rests against the seat head rest **1212**, the vibratory device **1200** overlays a portion of the head of the subject and is capable of transferring vibratory signals to the head. In some embodiments, the vibratory device can be removably attached to the seat **1210** using a support element **1218** such that it can be removed when not in use.

FIG. **14** illustrates another embodiment of vibratory devices **1300a**, **1300b** that may be integrated into, or connected to, a pair of eyeglasses **1310**. While eyeglasses are depicted in FIG. **14**, one of ordinary skill in the art would recognize that other types of eyewear (e.g., goggles, sun-

glasses, safety glasses) may also be suitable for having one or more vibratory devices. The vibratory devices **1300a**, **1300b** can be positioned on the eyeglasses **1310** on the ear portions **1311a**, **1311b** that may be in proximal contact with a subject's head during use of the eyeglasses **1310**. The vibratory devices **1300a**, **1300b** can be positioned such that, when a subject wears the eyeglasses **1310**, the vibratory devices **1300a**, **1300b** overlay a portion of the head such that vibratory signals can be transferred to the head and onto the vestibular system.

FIG. **15** illustrates another embodiment of vibratory device **1420** mounted or integrated into a virtual reality device **1410** (e.g., a device that can be used to experience virtual reality or augmented reality environments). The vibratory device **1400** can be positioned on the virtual reality device **1410** on a band **1441** of the virtual reality device **1410** that may be used to fasten or support the virtual reality device **1410** on the subject's head, and may be in proximal contact with the head during use of the virtual reality device **1410**. One or more vibratory devices may be mounted in any position along the band **1441** of the virtual reality device **1410**. The vibratory device **1400** may be positioned on the virtual reality device **1410** such that when the subject wears the virtual reality device **1410**, the vibratory device **1400** overlays a portion of the head of the subject such that vibratory signals can be transferred (e.g., via a delivery interface) to the head and onto the vestibular system.

In a further embodiment, a system may comprise a vestibular device described herein integrated into, or connected to (a) a soldier's helmet or any other form of helmet, or (b) a pilot's headset or any other type of headset. As before, the system may include the necessary power source (e.g., battery) and electrical driving circuitry. Such a system may de-stimulate the vestibular system of a pilot, thus allowing the pilot to rely on an airborne vehicle's (e.g., a plane) instruments for orientation.

FIGS. **17A** and **17B** illustrate example waveforms of electrical signals for powering a vibratory device. FIG. **17A** shows a sinusoidal waveform **1600**, with a wavelength **1604** and an amplitude **1602**, that can, for example, be used to modulate a magnetic field vector to move a vibratory element of a vibratory device. FIG. **17B** illustrates a square waveform **1610** that can, for example, be used to modulate a piezoelectric vibratory element in a vibratory device to generate vibratory signals, as described above. The piezoelectric device can vibrate at a high frequency to generate pressure when activated by the square wave, and the square wave can cycle at a lower frequency (e.g., less than 200 Hz) such that the pressure cycles on and off at the lower frequency of modulation (e.g. 60 Hz), and functions similarly to a low frequency vibratory signal.

FIG. **18** is a graph **1700** that depicts ramping up and ramping down of an electrical signal for powering a vibratory device to generate a vibratory signal. The graph **1700** shows how an amplitude of the electrical signal changes over time. As shown in FIG. **18**, the amplitude can be ramped up during an onset phase **1702**, where the amplitude is increased at a predefined rate. Upon reaching a predefined level, the amplitude is kept constant during a steady state phase **1706**, which may last for any suitable amount of time for treating a vestibular condition (as represented by the dashed line). The amplitude can then be ramped down at a predefined rate until the signal is turned off. The onset phase **1702** and the offset phase **1704** of the waveform can have different ramp profiles, as shown in FIG. **18**. For example, the increase of applied voltage amplitude in the onset phase **1702** can be a ramped increase with a certain rate of increase

in amplitude per unit time. And the offset phase **1704** can be a downward ramp or a ramped decrease in amplitude, with a certain rate of reduction of amplitude per unit time that is different from that of the rate of increase. In some embodiments, the rate of increase in amplitude in the onset phase **1702** can be higher than the rate of decrease of amplitude in the offset phase **1704**, as indicated by the different slopes. In some instances, the ramped increase in the onset phase **1702** and/or the ramped decrease in the offset phase **1704** can also be accomplished with a changing rate (e.g., a rate that increases and/or decreases over time).

In some instances, the rate of increase and/or the rate of decrease can be specified based the vestibular condition being treated, a subject's personal preferences, environmental factors, etc. In some embodiments, the rate of increase and/or the rate of decrease in amplitude can be adjusted by a user. In some embodiments, the rate of increase and/or the rate of decrease in amplitude can be automatically adjusted (e.g., by a control unit **360**) based on sensor readings. For example, a sensor integrated into a vibratory device can be configured to measure bodily or physiological conditions and/or reactions (e.g., changes in perspiration, temperature, heart rate, etc.) as the vibratory device is powering on and/or powering off. By monitoring bodily conditions and/or reactions, a ramp up and/or ramp down rate can be adjusted to accommodate different reactions (e.g., by a more sensitive or first-time user vs. a more regular user of the device). Moreover, for subjects that suffer from a chronic condition (e.g., vertigo), the ramp up and/or ramp down can be selected to reduce jarring effects of transitioning between the device turning on and/or off, such as, for example, a sudden return of the vestibular condition and greater on-set of symptoms associated with the vestibular condition.

FIG. **19** illustrates a method **1800** for using a vibratory device (e.g., vibratory device **300**, **400**, **500**, **600**, **700**) to treat symptoms associated with vestibular conditions disclosed herein. At **1802**, the vibratory device is positioned on the head of the subject or user. The positioning is over a suitable area (e.g. over a suitable bone structure) such that vibratory signals can be effectively transferred to the vestibular system of the subject.

At **1804**, an electrical signal is supplied to the vibratory device to energize the device and cause movement of the vibratory element in the vibratory device. At **1805**, the vibratory signals are applied to the subject's head to treat the vestibular condition. At **1806**, information associated with the energized vibratory device is monitored, including, for example, current, voltage, magnetic field fluctuations, etc. At **1808**, physiological conditions and/or comfort level of the subject is monitored. For example, the physiological signs like heart rate, perspiration, temperature, breathing, oxygen saturation, etc, of the subject can be monitored. In some instances, any feedback from the subject such as feedback reporting a level of comfort or discomfort perceived by the user, can be monitored using appropriate sensors and actuators integrated with the vibratory device. Such monitoring at **1806** and **1808** can be accomplished using one or more sensor(s) (e.g., sensor **390**, sensor **416**), and/or a control unit (e.g., control unit **360**).

At **1810**, the vibratory device and/or a control unit coupled to the vibratory device determines whether the electrical signal should be adjusted or changed. If the electrical signal does not need to be adjusted (**1810**: NO), then the vibratory device can continue treating the vestibular condition, at **1805**, with continued monitoring of information associated with the vibratory device, at **1806**, and

continued monitoring of information associated with the subject, at **1808**, as described above.

When the electrical signal does need to be adjusted (**1810**: YES), at **1812**, a frequency or a force level of the electrical signal is changed and the new electrical signal is applied to the vibratory device, at **1804**, following the flow chart as described above. The information collected from monitoring the vibratory device and from monitoring the subject can be used to determine whether the force level and/or the frequency need to be changed and by how much and in what form. For example, if measured voltage, current, and/or magnetic field fluctuations indicate that the current frequency is not the resonant frequency, then the frequency may be adjusted to improve an efficiency of the vibratory device. As another example, if a signal is received from a user indicating that the vestibular condition is no longer present (e.g., motion sickness is no longer present), then the vibratory device may adjust the frequency to turn off the device (e.g., via a ramp down). As another example, in response to an indication of discomfort by the subject, the force level may be decreased.

Experimental studies were conducted to test an experimental vibratory device, similar to example vibratory devices disclosed herein, for treating symptoms associated with vestibular conditions. The experimental vibratory device included a vibratory element implemented as a magnet suspended between two other magnets, similar to the vibratory device **500** depicted in FIG. **6**. The vibratory device included an outer coil with an impedance of four ohm, which was energized by a microcontroller, a custom-designed Arduino board. The microcontroller could energize the outer coil to generate a magnetic field, which was used to vibrate the suspended magnet. The three-magnet/voice coil assembly was placed inside a body or housing, and was connected to and powered by a rechargeable battery. The vibratory device could be coupled to a human head, and was capable of generating vibrations that could be conducted via bone to a vestibular system.

In the studies, subjects wore the experimental vibratory device placed behind an ear against an area overlaying the mastoid bone, such that vibratory signals generated by the device could be conducted via bone to the subjects' vestibular systems. Subjects were subjected to various conditions to induce motion sickness, nausea, and/or other vestibular conditions, and the effects of the vibratory devices were evaluated based on information reported by subjects.

For the experiments, the force level of the vibrations produced by the vibratory device was measured with a calibrated Brüel & Kjær (B&K) artificial mastoid (No. 4930) coupled with a B&K sound level meter (No. 2209). The vibratory device was inserted in a holder in the B&K, artificial mastoid designed for holding a bone conduction hearing aid. A force of eight Newtons was applied on top of the vibrating device, which sat against the B&K artificial mastoid. Bone conduction levels were quantified with the B&K sound level meter and are expressed as dB re 1 dyne (i.e., a force level).

Further information regarding each of the studies are provided below.

#### Experimental Study I

FIG. **20A** depicts a flowchart **1900** of a procedure for a first experimental study. Study participants in this first experimental study did not suffer from a history of vestibular maladies, including dizziness. During the duration of the study, participants were seated in an office chair and asked

to wear the Oculus Rift DK2 virtual reality system and a vibratory device, according to the example design described above. The vibratory device was held in place with a head strap.

The study was conducted according to the test procedure outlined in FIG. **20A**. Each participant went through the test procedure multiple times, first with the vibratory device turned off and then with the vibratory device turned on. During the tests with the vibratory device turned on, the frequency and/or the force level of the vibratory device was varied to test whether particular frequencies and/or force levels would be more effective at treating vestibular conditions associated with using a virtual reality device. During the tests, the order of the frequencies and/or force levels was randomized between participants. Participants were also given the opportunity to pause the study at any time to recover from dizziness or other vestibular conditions caused by the use of the virtual reality device.

At **1902**, the participant is presented with the visual stimulus **1950** depicted in FIG. **20B** via the display of the virtual reality device. The visual stimulus **1950** includes a disc-shaped region **1956** with a plurality of spheres **1954**. Participants were instructed to focus their attention on a central sphere **1952** that was of a different hue than the rest of the spheres **1954** in the disc-shaped region **1956**. The disc-shaped region **1956** was designed to represent a three-dimensional space that may be viewed using a virtual reality device, such as the Oculus Rift.

At **1904**, the participant initiates a rotation of the spheres **1954** in the disc-shaped region **1956** about a central point (i.e., the central sphere **1952**) by pressing a spacebar on a keyboard. Upon pressing the spacebar, the spheres **1954** would begin to spin, gradually accelerating at a rate of 4 degrees/second/second, at **1906**. Participants were instructed to press the spacebar again when they felt discomfort or dizziness, at which point the angular velocity of the spinning spheres **1954** would be recorded and stored as the "maximum angular velocity" for that participant, at **1908** and **1909**. If a particular participant did not press the spacebar to indicate discomfort or dizziness, then the angular velocity of the spheres **1954** would increase until it reached a predefined angular velocity of 90 degrees/second.

At **1910**, the angular speed of the image would be reduced to 90% of the speed before the user's indication (i.e., 90% of the speed recorded as the "maximum angular velocity") or, when the participant did not press the spacebar, 90% of 90 degrees/second (i.e., 81 degrees/second). The spheres **1954** are rotated at the reduced speed until the participant presses the spacebar again to indicate a return of discomfort or dizziness, at **1911**, or until a predefined amount of time (e.g., 120 seconds) has passed, at **1912**. Upon either the participant's indication, at **1911**, or the predefined amount of time passing, at **1912**, the time that the participant has viewed the disc-shaped region **1956** at the reduced speed is recorded as the "Duration of Viewing Time."

For a given participant, the participant was asked to perform the test procedure first with the vibratory device turned off. The participant would undergo the test procedure two times, a first time with the spheres **1954** rotating in a clockwise direction and a second time with the spheres **1954** rotating in a counterclockwise direction. The same would then be repeated with the vibratory device turned on. Study participants were asked to wear the vibratory device behind their ears and level with the ear canal on a flat part of the mastoid bone. Participants were given time to rest between

the clockwise and counterclockwise tests (e.g. 10-60 seconds), as needed, to recover from any discomfort or dizziness.

Participants while using the vibratory device were asked to test either a set of different force levels or a set of different frequencies. For participants that tested different force levels, the frequency of the vibratory signals was kept constant (i.e., at 50 Hz), while the force level was set to 87, 92, 94, 96, 98, 99, 100, and 101 dB re 1 dyne. For participants that tested different frequencies, the power level of the vibratory signals was set to a constant level (i.e., 96.5 dB re 1 dyne) and the frequency was varied between 30 and 75 Hz.

Eighteen participants participated in the study. Approximately one third of these participants who volunteered for the study did not experience any motion sickness from the experiments. These participants watched the visual stimulus that was presented (FIG. 20B) until the spinning spheres 1954 reached 90 degrees/second, and then continued watching the visual stimulus for 120 seconds at a reduced speed. These motion-sickness-resistant participants were instructed to repeat their exposure to the visual stimulus with the vibratory device turned on to test whether vibrations from the device would induce motion sickness. None of these participants reported that they experienced any negative side effects during and after using the vibratory device with the vibrations produced by the vibratory device being set to 97 dB re 1 dyne or below.

The experimental data for the remaining eleven participants (i.e., those that indicated that they experienced motion sickness or dizziness at some point during the experimental study) is depicted in FIGS. 21A, 21B, 22A, and 22B. For the data points in the graphs depicted in FIGS. 21A, 21B, 22A, and 22B, the clockwise and counterclockwise “Maximum Angular Velocity” and “Duration of Viewing Time” were averaged for each participant under each test condition, and the “with vibratory device” data was baseline-normalized based on the “without vibratory device” data (i.e., data collected for a participant while using the vibratory device set to a particular frequency and/or force level was normalized based on that participant’s data while not using the vibratory device). After calculating these ratios for each participant, the ratios of the eleven participants were averaged to arrive at the data point depicted in the graphs shown in FIGS. 21A, 21B, 22A, and 22B.

FIG. 21A depicts a graph 2000 of the average “Duration of Viewing Time” ratios of the eleven participants across a range of different force levels. Values greater than one indicate an increase in an amount of viewing time before discomfort is experienced while using the vibratory device versus not using the vibratory device. FIG. 21B shows a graph 2002 of the average “Maximum Angular Velocity” ratios of the eleven participants across a range of different force levels. Values greater than one in FIG. 21B indicate an increase in angular velocity that did not cause discomfort while using the vibratory device versus not using the vibratory device. The experimental data showed that for the eleven participants, the vibratory device had a greatest effect when the force level of its vibrations were set to 96 dB re 1 dyne. Based on an interpolated fit of the data, the “Duration of Viewing Time” and “Maximum Angular Velocity” ratios peaked at 96.5 dB re 1 dyne. “Duration of Viewing Time” and “Maximum Angular Velocity” ratios at force levels ranging from 93 dB to 98 dB were statistically significant different from, and greater than, one, indicating that a vibratory device set to these force levels would be effective at treating a vestibular condition.

At 87 dB re 1 dyne, the ratios were not statistically different from one, indicating that the device would not be effective at treating a vestibular condition. At levels around or above 100 dB re 1 dyne, many participants reported feeling worse with the vibratory device turned on. While the threshold of discomfort at these higher force levels was slightly different among participants, with some reporting discomfort at levels as low as 99 dB, once that threshold was reached for a particular participant, the participant would report that the vibrations made them feel uncomfortable almost immediately. Participants tested at 102 dB all reported feelings of discomfort, regardless of whether they were using the virtual reality system as the vibrations from the vibratory device alone caused them discomfort.

FIGS. 22A and 22B depict normalized and averaged “Duration of Viewing Time” and “Maximum Angular Velocity” ratios for the eleven participants across a range of frequencies. As shown, these results indicated that the effectiveness of the experimental vibratory device at mitigating or delaying the onset of virtual reality sickness does not appear to be dependent on the frequency of the vibratory signals. Nonetheless, the graphs 2100 and 2102 show greater ratio values from 45 to 65 Hz.

Certain factors may have limited the results of this first experimental study. For example, the angular velocity of the spheres 1954 in the disc-shaped region 1956 was limited by the visual display system. Specifically, the refresh rate of the Oculus DK2 screen is 90 Hz. The panels of the device are organic LED (OLED), with a persistence of 2 milliseconds. These factors prevented the rotational speed of the spheres 1954 in the disc-shaped region 1956 from rotating beyond approximately 90 degrees/second. As the rotational speed was increased beyond 90 degrees/second, the virtual reality display would start to flicker. Many test participants reached this upper limit while wearing the vibratory device, which caused a ceiling effect in the measurements.

Similarly, while viewing the spinning spheres 1954 at the reduced speed, several subjects complained of eyestrain, with no complaints of discomfort or nausea. Thus, participants were also limited in how long they could watch a rotating disk, which was another factor that led to a ceiling effect in the measurement of the effectiveness of the experimental vibratory in delaying the onset of virtual reality sickness.

Taking these factors into account, this first experimental study showed that the vibratory device was effective at treating virtual reality sickness at statistically significant levels. From the data shown in the graphs in FIGS. 20A and 20B, it was shown that variations in force level would have a statistically significant effect on the effectiveness of the vibratory device. Specifically, it was shown that force levels below 93 dB re 1 dyne were not effective at treating vestibular conditions and that force levels above 100 dB caused discomfort and dizziness that worsened vestibular conditions; therefore, the data indicated that force levels between 93 dB and 98 dB re 1 dyne were more effective at treating vestibular conditions. On the other hand, the data shown in the graphs in FIGS. 21A and 21B showed that varying vibration frequency had a smaller effect on the effectiveness of the vibratory device at treating vestibular conditions, as the effectiveness of the vibratory device did not have a clear trend or peak between 45 Hz to 65 Hz.

#### Experimental Study II

In a second experimental study, using the results obtained from the first experimental study, disclosed above, the

effectiveness of the experimental vibratory device at mitigating or preventing motion sickness experienced by users of the virtual reality game “EVE: Valkyrie” was measured.

“EVE: Valkyrie” is a first-person spaceship shooter game in which a player moves around a field of spaceships and space rocks using an Xbox 360 handheld controller. The game has been known to induce motion sickness in many players. The game involves flying through “gates” placed in a field of asteroids and spaceships. In addition to movement in the three spatial dimensions, most “gates” require the player to rotate around a three-dimensional rotational axis (e.g., a “roll,” “pitch,” or “yaw” axis).

In this study, subjects played the virtual reality game “EVE: Valkyrie” for up to fifteen minutes, using an Oculus Rift CV1 system. For the study, participants were instructed to play the game in two sessions, on two consecutive days, with and without using the experimental vibratory device described above. On the first day of experiments, participants were asked to play a training mission portion of virtual reality game for up to fifteen minutes without using the experimental vibratory device. Participants were instructed to stop if they began to feel nauseated before the end point of fifteen minutes. Experienced gamers could choose to go directly to the mission, bypassing the training mission and launching directly into a virtual reality space fight. On the second day, the same experimental procedures were followed, but with participants wearing the experimental vibratory device, which was set to a frequency of 60 Hz and a force level of 96.5 dB, which were found to be effective per the results of the first experimental study. The device was applied to the skull, behind the right ear and level with the ear canal and onto the flat part of the mastoid, with an applied force of approximately 8 Newtons. During the study, any participant who felt dizzy or uncomfortable could stop at any time of their choosing.

Participants were asked to fill out a Motion Sickness Assessment Questionnaire (“MSAQ”), approximately ten minutes after they stopped playing the game. The MSAQ involves sixteen statements or manifestations that help identify and categorize independent descriptors of motion sickness by grouping them into four categories of motion sickness: (1) gastrointestinal, (2) central, (3) peripheral, and (4) sopite. MSAQ scores range from 1 (not at all) to 9 (severe) for the sixteen possible manifestations of motion sickness. Table 1 shows the sixteen statements of the MSAQ used to assess motion sickness experienced by the participants.

TABLE 1

Motion Sickness Assessment Questionnaire, administered ten minutes after the end of the Oculus Rift playing experience described in Experimental Study II. MSAQ results, without and with device respectively		
1. I felt sick to my stomach (G)	2.9 ± 0.6	1.3 ± 0.2
2. I felt faint-like (C)	2.7 ± 0.4	1.2 ± 0.1
3. I felt annoyed/irritated (S)	2.7 ± 0.4	1.4 ± 0.2
4. I felt sweaty (P)	3.2 ± 0.6	1.6 ± 0.2
5. I felt queasy (G)	3.1 ± 0.5	1.6 ± 0.3
6. I felt lightheaded (C)	4.7 ± 0.6	1.6 ± 0.2
7. I felt drowsy (S)	3.5 ± 0.6	1.4 ± 0.2
8. I felt clammy/cold sweat (P)	2.5 ± 0.5	1.08 ± 0.08
9. I felt disoriented (Q)	3.5 ± 0.5	1.5 ± 0.6
10. I felt tired/fatigued (S)	3.8 ± 0.6	1.3 ± 0.1
11. I felt nauseated (G)	3.3 ± 0.6	1.5 ± 0.2
12. I felt hot/warm (P)	3.8 ± 0.7	1.4 ± 0.2
13. I felt dizzy (C)	4.1 ± 0.7	1.7 ± 0.2
14. I felt like I was spinning (C)	3.1 ± 0.5	1.25 ± 0.1
15. I felt as if I may vomit (G)	1.9 ± 0.4	1.0 ± 0.0

TABLE 1-continued

Motion Sickness Assessment Questionnaire, administered ten minutes after the end of the Oculus Rift playing experience described in Experimental Study II. MSAQ results, without and with device respectively		
16. I felt uneasy (S)	3.3 ± 0.6	1.5 ± 0.2
Not at all	Severely	
1—2—3—4—5—6—7—8—9		

10 G: Gastrointestinal  
P: Peripheral  
C: Central  
S: Sopite-related

When participants were asked to engage in play for fifteen minutes without wearing the experimental vibratory device on the first day, eleven of the seventeen participants were able to play for the full fifteen minutes. The duration of play for the remaining six ranged from 4:05-14:50 minutes. The average playing time was 13:25 minutes. By contrast, when participants wore the experimental vibratory device while playing, all 17 participants were able to engage in play for the duration of 15 minutes. Data from the MSAQ was collected and is presented in Table 1. The scores in the MSAQ range from 1 (not at all) to 9 (severe).

The results of the MSAQ are presented in graphical form in FIGS. 23A and 23B. Each graph depicts a ratio of the MSAQ scores obtained while not wearing the device over the MSAQ scored obtained while wearing the device. FIG. 23A depicts a plot 2200 that shows the mean scores from the MSAQ across all four categories of motion sickness, and FIG. 23B depicts four subplots 2202, 2204, 2206, 2208 that show the scores for the four categories of motion sickness defined by the MSAQ—specifically, (1) gastrointestinal, (2) central, (3) peripheral, and (4) sopite, respectively. The line 2250 through each graph represents when the MSAQ scores with and without using the vibratory device are the same, and therefore is the line that represents when the vibratory device has no effect on motion sickness.

As depicted in FIGS. 23A and 23B, the data indicates that the vibratory device was effective at treating motion sickness, as all the data points were situated below the line 2250. The data points indicated a significant reduction in the MSAQ score from 9 (severe) to 1 (not at all). Even when broken into the different categories of motion sickness, as shown in plots 2202, 2204, 2206, 2208 in FIG. 23B, the vibratory device was significantly effective in each category at treating motion sickness.

## Experimental Study III

In a third experimental study, participants were asked to be rear seat passengers in a four-door sedan and were driven on a segment of road based on a fixed 20-minute itinerary. Three road tests were conducted on the same day, on this set route. During each drive, the participants were asked to read an article on their smartphone or other small handheld device. The start time was recorded, and each participant reported the time at which they first felt first symptoms of motion sickness.

With each participant, a baseline measurement of motion sickness was established by having the participant undergo the drive and read an article on his or her smartphone without wearing any type of assistive device. After the initial drive, each participant was asked to wear (1) the experimental vibratory device as described herein placed overlaying the participant’s right mastoid bone, or (2) a sound generator that faced outwards and was isolated from a

participant's head by a rubber pad and that emitted a low frequency tone that provided an auditory level equivalent to the experimental vibratory device. The order of wearing each device was randomized for each participant.

The driving route was a fixed circuitous route with only one stop sign at the midway point (i.e., at approximately ten minutes) and no traffic lights. The fixed route took approximately 20 minutes, and the drive-to-drive variability was less than 10%. Subjects were only tested on the first half of the ride, up to the stop sign. Subjects were provided with rests between sessions.

Based on feedback from the participants, the study showed that the participants did not experience motion sickness continuously but generally did when the vehicle accelerated, decelerated, or made turns. Participants reported motion sickness as a cumulative effect, with the first turn inducing mild discomfort, the second turn adding to the effect of the first turn and so on, until a threshold was reached. While using the experimental vibratory device, participants reported that during the accelerations and turns, they felt discomfort, but this discomfort quickly returned to zero once the car went back to a constant speed, with no effect of accumulated nausea during the successive changes in the car's acceleration.

FIG. 24 depicts seconds to the initial onset of motion sickness that was experienced by participants during the third experimental study. Bar 2302 represents the seconds until initial onset of motion sickness with no device, bar 2304 represents the seconds until initial onset of motion sickness with the sound generator, and bar 2306 represents the second until initial onset of motion sickness with the experimental vibratory device. As shown, the use of the experimental vibratory device described herein led to a significant increase in the seconds to onset of motion sickness, at bar 2306. Specifically, the experimental vibratory device was found to be effective in that it more than doubled the time to onset of motion sickness compared to not wearing a device (bar 2302) and wearing a sound generator (bar 2304). The data of this study shows the effectiveness of the experimental vibratory device at preventing motion sickness in a simulated real-world situation of reading while riding as a passenger in the back seat of a car. None of the subjects who used the experimental vibratory device reported any feeling of discomfort once they got out of the car.

#### Summary of Experimental Studies and Other Indications

The results from the experimental studies described above show that a vibratory device, such as the example vibratory devices disclosed herein, can be effective at treating symptoms of various vestibular conditions. Such a device can have a small profile and be capable of coupling to a surface of a subject's head such that vibrations can be conducted via bone (e.g., the skull) to the subject's vestibular system. The experimental vibratory device used in the three experimental studies has been shown to be effective at mitigating and reducing motion and/or virtual reality induced motion sickness. The described experiments and results demonstrate that the effectiveness of the disclosed vibratory device in reducing motion sickness is substantially instantaneous, with no overt deleterious side-effects.

Subsequent experiments have shown that the force levels and frequency levels discovered to be effective herein were also effective at reducing vertigo and nausea brought on by caloric testing conducted at medical facilities. For example, for vertigo, individuals who suffered from chronic or frequent vertigo episodes were asked to wear the experimental vibratory device and report the effects of wearing the device.

Generally, individuals reported less symptoms associated with vertigo when using the device. As another example, for caloric testing, an ear, nose and throat ("ENT") physician performed caloric testing on five subjects with and without wearing an experimental vibratory device. When not wearing the device on a first day, all subjects experienced nausea with one subject being unable to complete the test due to severe nausea. When wearing the device on a subsequent day, all five subjects reported significantly less nausea, including no nausea, and the subject unable to complete the test the first day was able to complete it wearing the device the second day. The tests on both days indicated same levels of vestibular function, with and without the vibratory device.

The application of vibratory signals to mask signals sent by the vestibular system that induce sickness, also known as vestibular masking, through the application of bone conducted vibratory signals, can be effective at mitigating numerous vestibular conditions. For example, vertigo brought on by a damaged vestibular system can be treated with applied bone-conducted vibratory signals. At times, however, vibratory signals can have adverse reactions if the applied vibratory signals are suddenly removed (e.g., when the vibratory device is turned off). In some embodiments, such as those detailed above, these adverse reactions can be minimized by gradually reducing the power of the applied vibrations over a period (i.e., having a ramp down in power) instead of abruptly turning off the device.

As another example, vestibular masking can be effective in mitigating motion sickness that occurs when individuals use virtual reality devices, such as those disclosed herein. Because virtual reality devices do not result in motion sickness at all times, in an embodiment, a vibrating device such that those disclosed herein can be operable to generate vibrations for masking the vestibular system when certain conditions and/or situations associated with inducing sickness are displayed and/or presented to a user of the virtual reality device. The vibrating device may be controlled, for example, by a microcontroller that is operable to store specialized instructions for controlling the vibrating element. Such instructions may be stored in onboard memory or in a separate memory. In addition, such instructions are designed to integrate specialized functions and features into the controller to perform certain functions, methods and processes related to treating conditions of the vestibular system. In an embodiment, the microcontroller can be programmed with instructions using a software development kit ("SDK").

It should be understood that electrical signals to control and/or drive the generation of vibratory signals may be generated by a microcontroller based on the stored instructions. These electrical signals may be communicated between the microcontroller and a vibratory device via wired or wireless (e.g., Bluetooth) methods. Further, the electrical signals may include a stored pattern of operation. For example, the stored instructions accessed by the microcontroller may be used by the microcontroller to generate a series of electrical signals that are sent to the vibrating element to cause the vibrating element to be turned "on" or "off" in a pattern that is advantageous to a specific user based on usage data that has been accumulated and stored in a device that includes the microcontroller and vibrating element. One pattern may involve a series of vibrations where the number of vibrations generated and applied over a time period (e.g., per minute) to a subject may be varied, while a second pattern may include a series of vibrations where the force level in a number of vibrations may be varied. Other types of electrical signals, such as those that

may be used to control the force level and frequency of vibrations generated by the vibrating element, may be sent to the vibratory device from the microcontroller based on data received from sensors. For example, an acceleration sensor may be included in a portable electronic device (e.g., mobile phone) to sense changes in a user's physical acceleration. In an embodiment, the microcontroller may be operable to receive data from the acceleration sensor indicating a type of acceleration that may lead to motion sickness. Accordingly, after receiving such data, the microcontroller may be operable to generate associated control signals and send such signals to the vibrating element. The vibrating element, in turn, may be operable to receive such control signals and generate vibrations that can be applied to the proprioceptive vestibular system in real-time to, for example, to pre-emptively minimize motion sickness. Alternatively, a stored roadmap that represents a path or course that may result in a user becoming sick due to motion sickness may be stored in the microcontroller or in the portable device along with GPS circuitry. In an embodiment, as the GPS circuitry indicates that the user is moving along the path or course and arrives at a position that may induce motion sickness, the microcontroller may be operable to generate associated control signals and send such signals to the vibrating element. The vibrating element, in turn, may be operable to receive such control signals and generate vibrations that can be applied to the vestibular system to, for example, to account for the possibility of motion sickness before the user reaches the position, for example.

It should be noted that several different types of medical tests, including caloric, VNG, and ENG tests are administered by audiologists and otolaryngologists to test the vestibular function of subjects. As a part of a test, a form of vertigo may be induced in the patient which may have the adverse side effect of causing nausea. Vestibular masking can be used to reduce the nausea experienced by such patients while undergoing these tests. Accordingly, the devices described herein may be included in a medical testing system that is used to complete such medical tests, or, alternatively, may be used (e.g., worn) in conjunction with such medical testing systems to relieve or reduce such adverse side effects.

In some embodiments, the apparatuses and methods described can be used for applications not related to treating of vestibular conditions. For example, some embodiments of the vibratory device can be used as a device to carry out haptic communication using suitable communication channels. In some instances, a method of communication that is silent and based on haptic sensation may be of use, such as in military or surveillance conditions. An embodiment of the vibratory device can be used, with suitable adaptations of reduced detectability such as invisible and inaudible use condition, to allow haptic communication between subjects such as operatives.

It will be appreciated that the present disclosure can be implemented according to one or more of the following examples.

#### Example 1

An apparatus, comprising: a vibratory device configured to apply a vibratory signal to a portion of a head of a user such that the vibratory signal can be conducted via bone to a vestibular system of the user and cause a portion of the vestibular system to move in a manner equivalent to that of a therapeutically effective vibratory signal applied to an area overlaying a mastoid bone of the user, the therapeutically

effective vibratory signal (1) having a frequency less than 200 Hz and a force level between 90 and 100 dB re 1 dyne and (2) being therapeutically effective to treat a physiological condition associated with the vestibular system.

#### Example 2

The apparatus of Example 1, wherein the vibratory device is engageable with at least one of: the area overlaying the mastoid bone of the user, an area behind a head of the user, or an area on a forehead of the user.

#### Example 3

The apparatus of Example 1, wherein, when the vibratory device is engaged with an area of the head other than the area overlaying the mastoid bone, the vibratory device is configured to apply the vibratory signal at a force level that is equal to or less than 14 dB greater than force level of the therapeutically effective vibratory signal.

#### Example 4

The apparatus of Example 1, wherein the physiological condition includes at least one of: vertigo, dizziness, motion sickness, virtual reality sickness, spatial discordance, sopite syndrome, or nausea.

#### Example 5

The apparatus of Example 1, wherein the vibratory device is an electro-mechanical transducer including: a housing defining a chamber; a magnet disposed within the chamber and configured to oscillate to produce the vibratory signal; at least one suspension element configured to suspend the magnet within the chamber such that the magnet can vibrate about an equilibrium position.

#### Example 6

The apparatus of Example 1, wherein the vibratory device is associated with a resonant frequency, the apparatus further comprising: a signal source configured to supply an electrical signal to the vibrating element to cause the vibrating element to vibrate; and a sensor configured to measure information including at least one of: a current of the electrical signal, a voltage change of the electrical signal across the vibratory device, a magnetic field generated near the vibratory device, and an acceleration of the vibratory device.

#### Example 7

The apparatus of Example 6, further comprising a processor configured to adjust a frequency of the electrical signal based on the information such that the electrical signal causes the vibratory device to vibrate at the resonant frequency.

#### Example 8

The apparatus of Example 1, wherein the force level of the therapeutically effective vibratory signal is between 93 and 98 dB re 1 dyne.

#### Example 9

An apparatus, comprising: a vibratory device configured to apply a set of vibratory signals to a portion of a head of



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a user such that the set of vibratory signals can be conducted via bone to a vestibular system of the user to treat a physiological condition associated with the vestibular system, the vibratory device associated with a set of resonant frequencies including a lowest resonant frequency that is less than 200 Hz, the set of vibratory signals collectively having an amount of power at the lowest resonant frequency that is greater than an amount of power at remaining resonant frequencies from the set of resonant frequencies.

## Example 10

The apparatus of Example 9, further comprising: a signal generator configured to generate an electrical signal; and an amplifier configured to amplify the electrical signal to produce an amplified electrical signal, the vibratory device configured to receive the amplified electrical signal and produce, in response to receiving the amplified electrical signal, the set of vibratory signals.

## Example 11

The apparatus of Example 9, wherein the lowest resonant frequency is between 50 and 70 Hz.

## Example 12

The apparatus of Example 9, wherein the physiological condition includes at least one of: vertigo, dizziness, motion sickness, virtual reality sickness, spatial discordance, sopite syndrome, or nausea.

## Example 13

The apparatus of Example 9, wherein the vibratory device is an electro-mechanical transducer including: an elongate member having a longitudinal axis; and a magnet configured to oscillate along the longitudinal axis of the elongate member to produce the set of vibratory signals, the elongate member extending through an opening of the magnet and configured to reduce oscillations of the magnet along an axis other than the longitudinal axis of the elongate member.

## Example 14

The apparatus of Example 9, wherein the vibratory device is an electro-mechanical transducer including: a spring configured to expand and compress along an axis; and a magnet mounted to the spring and configured to oscillate along the axis to produce the set of vibratory signals, the spring configured to reduce oscillations of the magnet along an axis other than the axis of the spring.

## Example 15

An apparatus, comprising: a vibrating device configured to apply a vibratory signal to a portion of a head of a user such that the vibratory signal can be conducted via bone to a vestibular system of the user to treat a physiological condition associated with the vestibular system, the vibrating element including: a housing defining a chamber; a magnet movable within the chamber to produce the vibratory signal; a suspension element configured to suspend the magnet at a position within the chamber; and a coil configured to generate a magnetic field to cause the magnet to move about the position.

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## Example 16

The apparatus of Example 15, wherein the magnet is a first magnet, and the suspension element includes: a second magnet configured to apply a force to the first magnet in a first direction; and a third magnet configured to apply a force to the first magnet in a second direction opposite to the first direction, the first magnet disposed between the second magnet and the third magnet in the chamber such that the second magnet and the third magnet collectively suspend the first magnet at the position within the chamber.

## Example 17

The apparatus of Example 15, wherein the suspension element includes a spring (i) having a first end attached to a portion of the housing and a second end attached to the magnet and (ii) configured to apply a force to the magnet to suspend the magnet at the position within the chamber.

## Example 18

The apparatus of Example 15, further comprising a mounting plate, the magnet defining an opening that extends from a first end to a second end of the magnet, the second end of the magnet attached to the mounting plate, the suspension element including a spring having a first end attached to a portion of the housing and a second end extending through the opening of the magnet and attached to a portion of the mounting plate.

## Example 19

The apparatus of Example 15, wherein the suspension element includes a spring coupled to the magnet and configured to apply a force to the magnet to suspend the magnet at the position, the spring having a spring constant that is associated with a natural frequency for the magnet that is less than 200 Hz.

## Example 20

The apparatus of Example 15, wherein the suspension element includes a solid elastic material that is coupled to the magnet and is configured to apply a force on the magnet to suspend the magnet at the position within the chamber.

## Example 21

The apparatus of Example 15, wherein the suspension element is configured to reduce movement of the magnet along an axis other than a longitudinal axis of the chamber.

## Example 22

The apparatus of Example 15, further comprising an elongate member that extends along a longitudinal axis of the chamber, the elongate member extending through an opening in the magnet and configured to reduce movement of the magnet along an axis other than the longitudinal axis of the chamber.

## Example 23

The apparatus of Example 15, wherein the suspension element is configured to suspend the magnet to reduce contact between the magnet and the housing.

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## Example 24

The apparatus of Example 15, wherein the physiological condition includes at least one of: vertigo, dizziness, motion sickness, virtual reality sickness, spatial discordance, sopite syndrome, or nausea.

## Example 25

A method, comprising: positioning a vibratory device over an area of a head of a user; energizing the vibratory device, after the positioning, to apply a vibratory signal to the area such that the vibratory signal can be conducted via bone to a vestibular system of the user, the vibratory signal configured to cause a portion of the vestibular system to move in a manner equivalent to that of a vibratory signal (1) applied to an area overlaying a mastoid bone of the user and having (2) a frequency less than 200 Hz and a force level between 90 and 100 dB re 1 dyne; and treating, in response to energizing the vibratory device, a physiological condition associated with the vestibular system.

## Example 26

The method of Example 25, wherein the physiological condition includes at least one of: vertigo, dizziness, motion sickness, virtual reality sickness, spatial discordance, sopite syndrome, or nausea.

## Example 27

The method of Example 25, further comprising securing the vibratory device over the area of the head using a rigid or elastic headband.

## Example 28

The method of Example 25, wherein the vibratory device includes a magnet, the energizing includes vibrating the magnet to generate the vibratory signal.

## Example 29

The method of Example 25, wherein the energizing includes: generating an electrical signal; amplifying the electrical signal to produce an amplified electrical signal; and supplying the amplified electrical signal to the vibratory device to cause the vibratory device to generate the vibratory signal.

## Example 30

The method of Example 25, the energizing including supplying an electrical signal to the vibrating element to cause the vibrating element to vibrate, the method further comprising: measuring, using a sensor, information including at least one of: a current of the electrical signal, a voltage change of the electrical signal across the vibratory device, a magnetic field generated near the vibratory device, and an acceleration of the vibratory device; and adjusting a frequency of the electrical signal based on the information such that the electrical signal causes the vibratory device to vibrate at a resonant frequency associated with the vibratory device.

While various inventive embodiments have been described and illustrated herein, those of ordinary skill in the art will readily envision a variety of other means and/or

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structures for performing the function and/or obtaining the results and/or one or more of the advantages described herein, and each of such variations and/or modifications is deemed to be within the scope of the inventive embodiments described herein. More generally, those skilled in the art will readily appreciate that all parameters, dimensions, materials, and configurations described herein are meant to be exemplary and that the actual parameters, dimensions, materials, and/or configurations will depend upon the specific application or applications for which the inventive teachings is/are used. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific inventive embodiments described herein. It is, therefore, to be understood that the foregoing embodiments are presented by way of example only and that, within the scope of the appended claims and equivalents thereto; inventive embodiments may be practiced otherwise than as specifically described and claimed. Inventive embodiments of the present disclosure are directed to each individual feature, system, article, material, kit, and/or method described herein. In addition, any combination of two or more such features, systems, articles, materials, kits, and/or methods, if such features, systems, articles, materials, kits, and/or methods are not mutually inconsistent, is included within the inventive scope of the present disclosure.

Also, various inventive concepts may be embodied as one or more methods, of which an example has been provided. The acts performed as part of the method may be ordered in any suitable way. Accordingly, embodiments may be constructed in which acts are performed in an order different than illustrated, which may include performing some acts simultaneously, even though shown as sequential acts in illustrative embodiments.

The invention claimed is:

1. A method, comprising:

applying, via a vibratory device positioned over an area of a head of a user, one or more vibratory signals to the area of the head of the user such that a portion of the one or more vibratory signals are conducted via a temporal bone to a vestibular system of the user, the one or more vibratory signals having a frequency between 30 and 80 Hz and a force level greater than 87 dB re 1 dyne and less than or equal to 101 dB re 1 dyne, the applying the one or more vibratory signals to the area of the head of the user causing movement of a portion of the vestibular system that treats a physiological condition associated with the vestibular system.

2. The method of claim 1, wherein the vibratory device has a resonant frequency, the method further comprising:

supplying an electrical signal to the vibratory device to cause the vibratory device to vibrate to generate the one or more vibratory signal that are applied to the area of the head of the user, the electrical signal having a signal frequency;

measuring, using a sensor, information including at least one of: a current of the electrical signal, a voltage change of the electrical signal across the vibratory device, a magnetic field generated near the vibratory device, and an acceleration of the vibratory device; and adjusting the signal frequency of the electrical signal based on the information such that the electrical signal causes the vibratory device to vibrate at the resonant frequency of the vibratory device.

3. The method of claim 1, wherein the physiological condition includes at least one of: vertigo, dizziness, motion

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sickness, virtual reality sickness, spatial discordance, sopite syndrome, nausea, headache, migraine, or tinnitus.

4. The method of claim 1, further comprising maintaining the vibratory device over the area of the head using at least one of: a rigid or elastic headband, a helmet, or an earcup.

5. The method of claim 1, wherein the vibratory device includes a magnet that is configured to vibrate to generate the one or more vibratory signal that are applied to the area of the head of the user.

6. The method of claim 1, further comprising:  
generating an electrical signal;  
amplifying the electrical signal to produce an amplified electrical signal; and  
supplying the amplified electrical signal to the vibratory device to cause the vibratory device to generate the one or more vibratory signal that are applied to the area of the head of the user.

7. A method, comprising:  
generating, via a signal generator of a vibratory device, an electrical signal having a signal frequency;  
delivering the electrical signal to a set of coils of the vibratory device such that the set of coils generates an alternating magnetic field;  
causing, via the alternating magnetic field, a vibratory element of the vibratory device to vibrate and generate one or more mechanical vibratory signals; and  
transferring, via a housing of the vibratory device in contact with an area of a head of a user, the one or more mechanical vibratory signals to the area such that at least a portion of the one or more mechanical vibratory signals are conducted via a temporal bone to one or more of an otolith organ or semicircular canal of a vestibular system of the user and causes movement of the one or more of the otolith organ or the semicircular canal that treats a physiological condition associated with the vestibular system,  
the one or more mechanical vibratory signals having a frequency between 30 and 80 Hz and a force level greater than 87 dB re 1 dyne and less than or equal to 101 dB re 1 dyne.

8. The method of claim 7, wherein the signal generator, the set of coils, and the vibratory element are disposed within the housing.

9. The method of claim 7, wherein the area of the head of the user is an area overlying a mastoid process of the temporal bone of the user.

10. The method of claim 7, wherein the force level of the one or more mechanical vibratory signals is between 93 and 98 dB re 1 dyne.

11. The method of claim 7, wherein the vibratory element includes a magnet and at least a portion of the vibratory element is suspendable in a space within the set of coils.

12. The method of claim 11, wherein the vibratory element is configured to vibrate along a longitudinal axis of the space.

13. The method of claim 7, wherein the vibratory device has a fundamental frequency of less than 200 Hz, the method further comprising:

measuring, via a set of sensors of the vibratory device, operational information of the vibratory device; and  
adjusting the signal frequency of the electrical signal based on the operational information to cause the vibratory element to vibrate at the fundamental frequency of the vibratory device.

14. The method of claim 13, wherein the fundamental frequency is between 50 and 70 Hz.

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15. The method of claim 13, wherein the set of sensors includes at least one of:

an ammeter configured to measure a current of the electrical signal;  
a voltmeter configured to measure a voltage of the electrical signal; or  
a Hall effect sensor configured to measure a magnitude of the magnetic field.

16. The method of claim 7, further comprising:

monitoring, using a set of sensors, a set of physiological conditions of the user including at least one of: heart rate, perspiration, temperature, breathing, or oxygen saturation; and  
generating the electrical signal based on the monitoring.

17. The method of claim 7, wherein the physiological condition includes at least one of: vertigo, dizziness, motion sickness, virtual reality sickness, spatial discordance, sopite syndrome, nausea, headache, migraine, or tinnitus.

18. A method, comprising:

generating an electrical signal using a signal generator;  
energizing a vibratory device using the electrical signal such that the vibratory device generates one or more mechanical vibratory signals;

contacting a portion of the vibratory device with an area of a head of a user to apply the one or more mechanical vibratory signals to the area such that at least a portion of the one or more mechanical vibratory signals are conducted via a temporal bone to one or more of an otolith organ or semicircular canal of a vestibular system of the user and causes movement of a portion of the one or more of the otolith organ or the semicircular canal that treats a physiological condition associated with the vestibular system, the one or more mechanical vibratory signals having a frequency between 30 and 80 Hz and a force level greater than 87 dB re 1 dyne and less than or equal to 101 dB re 1 dyne;

monitoring, while applying the one or more mechanical vibratory signals to the area of the head of the user and using a set of sensors, a state of the vibratory device or the user; and

adjusting a property of the electrical signal based on the monitoring to change at least one of the frequency or the force level of the mechanical vibratory signal.

19. The method of claim 18, wherein the state of the vibratory device or the user includes a set of physiological conditions of the user including at least one of: heart rate, perspiration, temperature, breathing, or oxygen saturation.

20. The method of claim 18, wherein the state of the vibratory device or the user includes one or more of: a movement of the vibratory device or the user, a location of the vibratory device or the user indicative of anticipated movement of the vibratory device or the user, or a virtual reality experienced by the user.

21. The method of claim 18, wherein the energizing the vibratory device includes:

delivering the electrical signal to a set of coils such that the set of coils generates an alternating magnetic field; and

causing, via the alternating magnetic field, a vibratory element of the vibratory device to vibrate to generate the one or more mechanical vibratory signals.

22. The method of claim 18, further comprising amplifying, using an amplifier, the electrical signal prior to using the electrical signal to energize the vibratory device,

the adjusting of the property of the electrical signal including adjusting an operation of at least one of the signal generator or the amplifier.

23. The method of claim 18, wherein the adjusting of the property of the electrical signal increases a comfort level of the user.

24. The method of claim 18, wherein the area of the head of the user is an area overlying a mastoid process of the 5 temporal bone of the user.

25. The method of claim 18, wherein the force level of the one or more mechanical vibratory signals is between 93 and 98 dB re 1 dyne.

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